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The Emerging Role of Robotics in Personal Health Care: Bringing Smart Health Care Home

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THE EMERGING ROLE OF ROBOTICS IN PERSONAL HEALTH CARE:

Bringing Smart Health Care Home

An Interactive Qualifying Project to be submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Abstract

The health care industry has come a long way in the past century. The demand for health care, however, continues to exceed the supply of affordable, accessible care due in large part to the rapidly aging baby boomer population. The quickly advancing field of robotics can provide an effective solution to this problem. Primarily, this project aimed to develop a set of user requirements for a personal health care robot. To generate these requirements, the team conducted interviews with robotics professionals, as well as focus groups with caregivers and our target demographic, the elderly. From these studies, the team gained an understanding of prominent and desired functionalities of robots, as well as what may influence their acceptance into the home setting. Additionally, the team developed a unique taxonomy to characterize the robots being investigated, the role of the end users, and their interaction with various types of robots. The requirements generated by the studies were then used in conjunction with the team's taxonomy to recommend a robot for use in personal health care that could potentially provide the most benefit to both the health care industry and the end users. An in-home patient monitoring system was found to have the greatest potential as an effective proactive solution to the issues currently facing the health care industry.

Executive Summary

The health care industry has come a long way over the past century, but as the population expanded, the demand for health care grew with it. Elderly Americans (age 65+) today account more than a third of the annual US personal health care expenditure while only making up about 13% of the US population. As the baby-boomer generation reaches seniority, the ratio of elderly people to the total population will rise. As patients begin to outnumber caregivers, the demand for health care will begin to rapidly outpace its supply. Additionally, the annual national personal health care expenditure will skyrocket, and proper care may become far less accessible as insurance companies become more selective with their clientele.

At a recent TEDMED conference, Colin Angle, CEO of iRobot, gave a presentation about these very same issues. He stated that today, "For every one person over 65, there's four under [65] that could provide care," but by 2030 the ratio of caregivers to elderly will be approximately 1-to-1. Angle also mentions the rising costs of nursing homes and health care, as well as inherent reluctance to give up independence by saying, "The cost of having someone in a nursing home today is over $10,000 per month[...]and three out of four seniors want to stay in their own homes" [1].

Fortunately, the industry is being revolutionized by the concept of smart health care – contextually aware systems that can help make decisions based on gathered information. The application of this advanced technology to health care has the potential to increase productivity of workers and of everyday operations at a relatively low cost. Robotics in particular could ideally make quality health care more accessible by complimenting existing human resources and improving the health of its users, essentially increasing supply (a reactive solution to an existing problem) and decreasing demand (a proactive solution to a potential problem) respectively. Our goal was to identify and justify an area of health care that may benefit most from the implementation of robotics and to develop a set of user requirements for an appropriate robot. The information we provide may help improve the efficiency of the health care industry, allowing proper care to be more accessible as well as affordable.

To identify an ideal application for robotics in personal health care, the team established the following objectives:

- Conduct a literature review of existing health care robotics technologies and determined any trends relating the robot's functionality to its user acceptance in its intended application;
- Create a taxonomy of robots and their interaction with users within the health care context;
- Determine user needs and preferences through interviews and focus groups with industry experts and potential users;
- Develop a set of requirements for a health care robot;
- Recommended a possible high-level design for a personal health care robot, based on our requirements.

Methods

In order to identify an area of health care that would be improved by the implementation of robotics, and to define the users associated with that particular area, the following methods were carried out:

- Literature review of background information pertaining to the health care industry and potential user demographics.
- Interviews with professionals in the field of robotics at the RoboBusiness Leadership Summit in Boston, MA.
- Focus groups at WPI and Summit ElderCare in Worcester, MA with potential and current caregivers, as well as elderly patients.
- Review of existing robot taxonomies and development of a unique taxonomy.

The information gathered from the literature review helped to define the problem statement and our further course of action. The interviews with robotics professionals at RoboBusiness gave the group a better idea of the current trends in the industry, namely the most rapidly growing areas of health care robotics. Conducting focus groups allowed the team to characterize the user and identify their needs and expectations. The studies provided data regarding the opinions of potential future and current users on various functionalities and perceptions of robots. The unique taxonomy was developed by the team in order to better characterize the relationship between health care robots and their users.

Results

From the information gathered during the RoboBusiness interviews and the WPI and Summit ElderCare focus groups, we were able to come up with a set of considerations and user requirements for designing a health care robot. The most important considerations we identified in our research are the robot's functionality (proactive vs. reactive functionality), price, ease-of-use, and the user's perception of robots (namely their attitudes towards privacy, artificial intelligence, appearance, and robot control). *From these considerations a set of requirements emerged: an ideal robot must provide the primary user with independence, emergency support, and a sense of security; the robot must be affordable or provide some value to secondary users that may compensate for some of its cost; finally, the robot must have an intuitive user interface to provide a seamless and convenient experience for the user.*

Recommendations

A robot with the capacity to monitor its user can fulfill the requirements we defined previously, and by following the recommendations discussed below, we are confident that such a robot can be successfully implemented in the home health care market. These recommendations will be useful for the health care robotics industry and help bring smart health care into the homes of patients.

We recommend a robot with a functional morphology.

Our studies have shown that people are not receptive to robots with an anthropomorphic (human-like) or zoomorphic (animal-like) appearance. Thus, allowing the robot's functionality to define its appearance is preferable. This design would allow the robot to be marketed not as a robot, but instead based on its functionalities and potential benefits, a strategy which would cater to consumers' apprehension to accept life-like robots.

We recommend a robot with a delocalized architecture.

Delocalized hardware will make the robot more adaptable, as components can be easily interchanged and upgraded, as well as make it more easily integrated into existing technology infrastructure.

We recommend a robot with a high ("combination") degree of autonomy.

The robot should function completely on its own, communicating to a supervisor (secondary user) only when necessary (i.e., in case of emergency or malfunction). The primary user should have few responsibilities concerning the robot's function and maintenance.

We recommend a robot with the sensing capacity to observe its user.

Observation of the user can range from tracking movement and daily activities (physical or visual sensors) to monitoring vital signs and detecting biomarkers associated with specific medical conditions (biosensors). The sensing capacity must be customizable to the user's needs and preferences.

We recommend a robot with the processing capacity to recognize emergency situations and the warning signs of diseases.

By storing collected data and correlating it to the user's known medical condition (as determined by doctor), a patient information database can be compiled and used in diagnosing diseases in their earlier stages. This can provide the proactive functionality that may compel insurance companies, hospitals, government, etc. to subsidize the cost of the robot for potential consumers.

We recommend a robot with the actuating capacity to communicate information to the secondary users, namely the primary user's relatives, care takers, and health care providers.

Once the robot detects an emergency or deterioration in the user's health, it must be able to communicate this information to the relatives, care takers, and health care providers responsible for the user. It is important that this action is carried out in real time, particularly in an emergency situation.

A monitoring robot would provide the user with enough independence to live at home on his/her own in addition to a sense of security knowing that reactive assistance will arrive promptly if an emergency were to occur. Adapted to a patient information database such as those being developed by hospitals around the country, such a robot would provide valuable data that could later be used to diagnose diseases at much earlier stages. The system would be able to proactively identify the warning signs of certain conditions from the data it collects by comparing that information to patterns in the database. In this way, a monitoring robot would provide not only an immediate, reactive response to health care shortages, but also a long-term, proactive solution to the issues that face both the elderly and the current health care industry.

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1 Introduction

Over the past several decades, robotics and its enabling technologies have allowed significant progress in many different industries. One industry that is beginning to be affected by this technological growth is the field of health care. Robotic surgery and automated materials-transporting robots have both made beneficial additions to the health care industry. Smart technologies, which are contextually aware systems that can help make decisions based on gathered information, have also aided in the advancement of the health care industry. This use of robotics and smart technology, however, has not been enough to counteract the rising cost of health care and the diminishing supply of medical personnel. Additionally, personal technology use and adoption rates are higher than ever before, indicating that more and more of the aging population of the United States is interested in new technology.

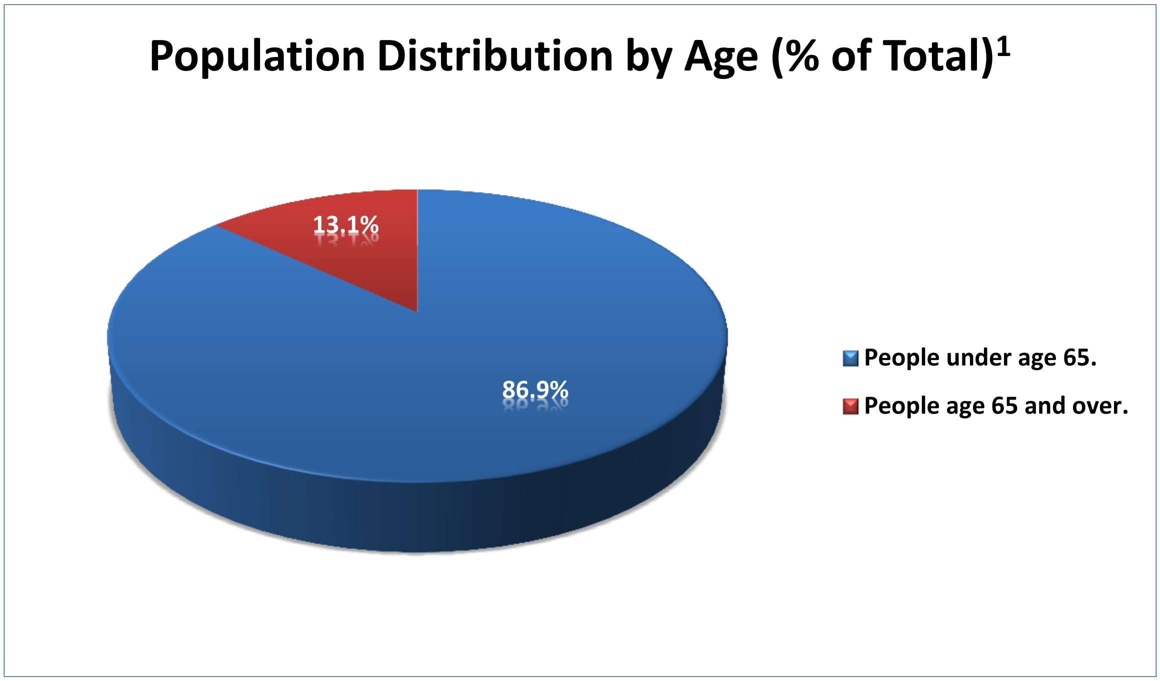
With the advancement of robotics and smart technologies, the increasing demand for affordable health care, and the widespread personal use of new technology, an opportunity arises for the use of robotics as personal home health care devices. Our project investigated this opportunity. Based on the feedback from potential users, the opinions of robotics professionals, and the team's own interpretations and taxonomy, we proposed a set of requirements for a personal home health care robot, and provided recommendations for a specific personal home health care robot that could both appeal to users and address current issues in the health care industry.

1.1 Motivation & Problem Statement

As our society expands in terms of both technology and population, it struggles to find an optimum balance between the two: technology must be applied in such a way that it strictly *complements* the human resource – an excess of technology (based on the need for services, not technology itself) may begin to displace workers and lead to unemployment and a lower standard of living, whereas a shortage of technology (again, based on the need for services, not technology itself) may lead to lower quality services and a lower standard of living for the people. This same balance applies to health care. People implement technology in health care in hope of improving productivity. One example is Swisslog's RoboCourier, a robotic transporter intended to be applied in a hospital environment [2]. The robot can maneuver around hospitals, bringing equipment and supplies to health care personnel. This eliminates the need for the human transport of materials, allowing the health care workers to focus more on their duties. However, the demand for health care is quickly outpacing the supply despite the attempts to increase productivity. This may be partially due to the growing and aging U.S. population, as is evidenced by hospital overcrowding and worker shortages [3].

As the baby-boomers grow older, the ratio of care givers to patients will continue to decline. It is evident even today that human resources are being strained by the demand for health care, the standard and expectations of which are constantly rising [4]. Not only are human resources becoming strained, but the cost of health care continues to grow as newer, more expensive technologies become the standard. One may argue that as medical technology improves, the cost of health care will likely decrease, but personal health care expenditures are projected to achieve an annual growth rate of 5.5 % by 2013 [5].

There are several factors that may be driving the growing national health care expenditure: As health care improves, people will have access to more basic medical necessities, such as vaccines, regular check-ups, etc., as well as be more educated about their own health – resulting in a longer average life-span among the population. A growing elderly population implies a higher incidence of medical conditions associated with older age: "the burden of delirium alone on the health care system ranges from $38 billion to $152 billion each year" [6]. Also, the continuous development of alternative treatment options will likely keep the cost of health care constant, if not cause it to increase, because patients will generally prefer the most effective treatment option (which will likely be the most recent as well as expensive). Today, adults over age 65 account for over a third of personal health care spending, despite representing less than an eighth of the population (see Fig. 1.1) [7], [8].



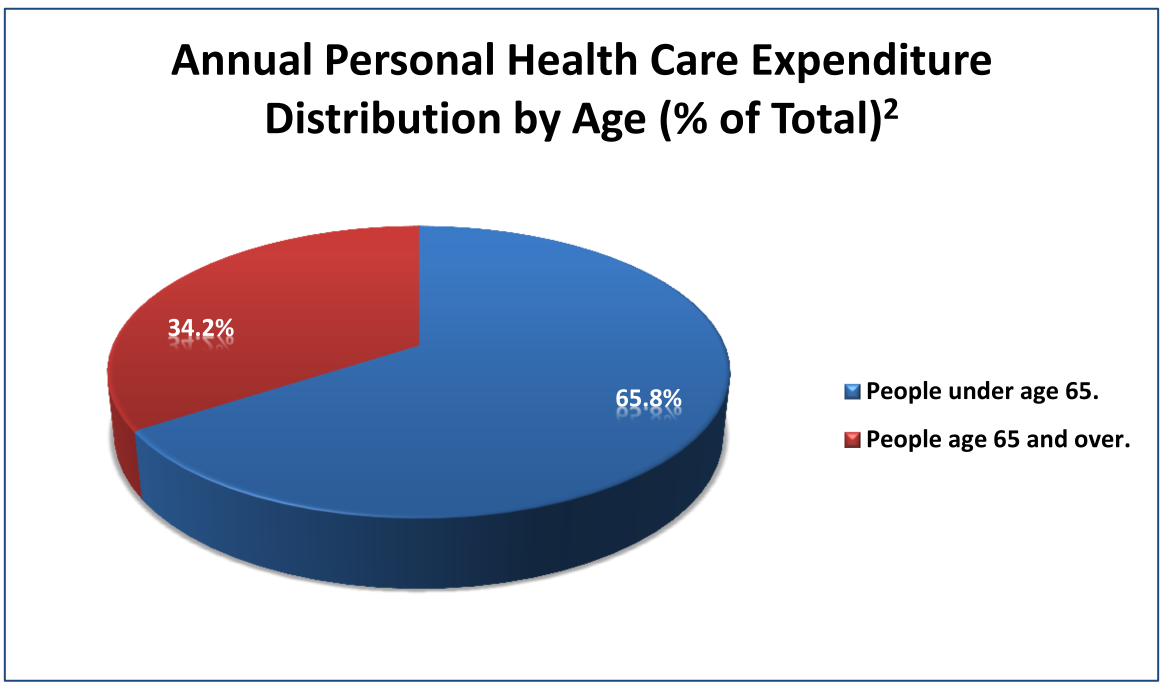


Figure 1.1- *Population Distribution vs. Healthcare Spending Distribution by Age* [1][7] [2][8]

Despite growing costs, the demand for health care is still steadily increasing. This is also due to the growing elderly population: As the ratio of old to young people increases, the amount of care demanded increases and the amount provided decreases. This is because there will be less young people to care for the elderly [1]. With the issues facing our aging population, it is apparent that elder care presents an opportunity for the implementation of robotics. An elder care robot may be able to compensate for the lack of care givers available, as well as provide patients with autonomy, prevent severe medical conditions from developing, and prevent errors in diagnoses and care in general by providing tangible data (data such as patients' medical condition, vital signs, eating/sleeping/hygienic habits, exercise habits, etc.) that doctors can use to make more informed decisions. The capabilities of current elder-care robots consist of assisting the elderly with self-maintenance activities of daily living (ADLs) such as eating, bathing, dressing, etc., instrumental ADLs such as cooking, cleaning, shopping, housekeeping, etc., and enhanced ADLs such as socializing, learning new skills, and engaging in hobbies [9]. After surveying 147 different elder care robots, Fausset et al. [9] determined that the self-maintenance and enhanced ADLs are most commonly focused on by robot designers.

It is clear that the rise in demand for quality health care will continue to strain both human and financial resources. One solution to this problem follows the "reactive" route: creating a way to provide more care to more people, a reaction to the increasing demand for health care. A more "proactive" solution, however, would be to optimize the current production of health care. In other words, engineers must find ways to either improve the quality of care vs. cost or lower the cost of care while maintaining the current standard at the very least. Herein lays *our* problem. We as a group believe that robotics has the potential to greatly improve the efficiency of the health care industry. In fact, it can benefit the industry in numerous fields – from diagnostics and surgery to rehabilitation and home care. These solutions can also be either clinical or consumer-facing. Our goal is to identify and justify an area of health care that may benefit most from the implementation of robotics and to develop a set of user requirements and recommendations for an appropriate robot. We hope that the information we provide may help improve the efficiency of the health care industry, allowing proper care to be more accessible as well as affordable.

1.2 Objectives

The ultimate goal is to develop a set of requirements that satisfy the health care needs and preferences of older adults in their home environments. To do this, we must first determine specifically where the best opportunity for the implementation of robotics exists, then identify and analyze the user(s)' needs and preferences, determine ways to define and classify robots, and evaluate the current applications of robotics in health care and other related fields. The objectives are summarized and sorted by order below:

- To conduct a literature review of existing health care robotics technologies and determine any trends relating the robot's functionality to its acceptance by the users in its intended application;
- To develop a taxonomy of robots and their interaction with users within the health care context;
- To determine user needs and preferences through interviews and focus groups with industry experts and potential users;
- To develop a set of requirements for a health care robot.

1.3 Approach

The rest of this report is organized as follows. The next chapter introduces our background research on key topics related to our project, including the health care industry, health care users, and the robotics industry. Chapter 3 presents our methodology, followed by Chapter 4 that includes our results from multiple focus groups and from our systematic literature review. Chapter 5 presents a discussion of our results, the set of requirements for a home health care robot, and our design recommendations for such a robot. Our report concludes with Chapter 6, where we summarize our findings and project the future of robotics in health care.

2 Background

The background section is intended to help better define and understand the problems in health care, and therefore the opportunity to implement robotics. The research also covers the definition of robotics, a preliminary taxonomy of robotics, and robotic technology currently being used in health care.

2.1 Health Care Overview

This section proposes an outlook in the health care industry worldwide where smart technology is taking place, creating innovative and affordable opportunities to satisfy the growing market. It also discusses about the current problems in the health care industry in the United States, exploring the ways that technology could potentially bring a better and smarter solution to health care and home care.

2.1.1 Smart Health Care

We are living in a world overwhelmed by information. The traditional health care industry is overrun with increasing demand of health care services providing customization or more personal services. People want to be more involved with making decisions on "proper" medical treatment methods, increasing the complexity of diagnostic services and creating a high likelihood of diagnostic errors at the same time. An estimated 15% of diagnoses are inaccurate or incomplete because physicians are overloaded by information [10]. In addition to the common occurrence of misinformed diagnoses, the growing shortage of qualified nurses and medical specialists is deteriorating the situation, both in developed and developing countries. According to the World Health Organization, one in every ten patients in developed countries is harmed when they receive hospital care. In some countries, the cost for additional hospitalization, litigation costs, lost income, disability, infections acquired in hospitals and medical expenses have totaled between 6 billion and 29 billion USD per year [11].

The concept of smart health care has been developed from a previous, similar concept: "intelligent health care technology." Intelligent health care technology refers to smart devices and systems that will perform certain functions in regards to their environment, assimilating information to support care decisions [12]. Our society is becoming more dependent on smart health care as the population increases and people become more conscious of their own health.

To improve the quality of care, patient safety, and outcomes, as well as maintain cost-effectiveness, health care facilities have been turning to technological solutions more frequently than ever before. This technological revolution has led to the idea of “smart” health care. *Smart* applies “scientific methods and knowledge bases of a broad range of computing and communication research perspectives” and brings innovations of computer, information science and engineering into health care [13]. With a focus in data integration, smart health care can benefit the population with a more organized system that provides “instrumented, interconnected and intelligent solutions” [14]. With easier access to information, the system also gathers and interprets data which help doctors make more informed decisions.

The application of an intelligent health care system is rapidly growing in areas such as surgery, rehabilitation, and prosthetics. Robotics, the new star in smart health care, has entered the industry with a combination of leading edge technology in engineering and computer to improve the quality of health care services. Personal and home robots are growing rapidly. Medical robotics aided with cardiac surgery and remote surgery is in increasing demand and so is robotics for routine hospital tasks. Fig. 2.1.1 displays the basic areas in the domain of health care. The application of robotics can aid health care system run more smoothly in the areas of remote surgery, professional care, rehabilitation treatment and activities of daily living.

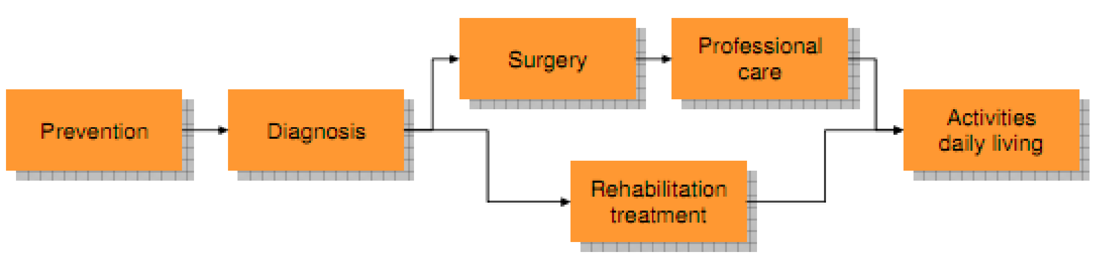


Figure 2.1.1 – *Domain of Health Care* [15]

2.1.2 Persistent Issues

The current barriers to providing appropriate health care treatment in the United States are the shortage of qualified health care personnel, inability to provide critical in-time treatment for medical emergencies, the immature industry regulations, and the financial restrictions. Analyzing the persistent issues in the health care industry helps the team determine the best opportunity for robotics to improve the current health care performance.

Strained Human Resources

The quality of health care personnel (including physicians and nurses with corresponding certificates) is a crucial factor in the successful treatment of patients. However, the gap is widening between the increasing patient demand and the qualified health care personnel. In a prediction by the federal government, around 24,000 doctors and nearly one million nurses will be retired by 2020 [16].

Hospital nurse staffing is a major concern because they have huge effects over patient safety and quality of care. Patients have poorer performance in pneumonia, shock, cardiac arrest, and urinary tract infections when the hospital has lower nurse staffing levels [17]. The number of nurses is expected to grow by only 6 percent by 2020, while demand for nursing care is expected to grow by 40 percent. A Federal Government study predicts that hospital nursing vacancies will reach 800,000 or 29 percent, by 2020 [18]. The structural feature in the long term produces a vicious cycle: the aging of the nursing population and “the increasing unwillingness of young women to consider nursing as a profession” generate a gap between increasing need for professional care and professional care providers [19].

Common Life-Threatening Medical Emergencies

Time plays a determined role in health care and it can save lives when treated in time. Some common life-threatening medical emergencies include stroke, cardiac arrest (myocardial infarction or heart attack), and seizure. Time-critical treatment usually makes a tremendous difference in these cases.

Stroke is the U.S.'s third leading cause of death. Among the 374 patients who had an ischemic stroke diagnosed in the Emergency Department (ED), 4.3% received tissue plasminogen activator (tPA) within 3 hours of stroke onset. Treatment rates could have increased to 28.6% if all patients had called 911 immediately, to 5.7% if transport time was instantaneous, and to 11.5% if all eligible patients who arrived in the ED within 3 hours were treated. If all three response times were optimized, 57% of the patients could have been saved, that is to say, more than half of the patients' fates would have changed with in-time treatment [20].

A study conducted with 874 pre-hospital cardiac arrest patients shows that the delay of the initiation of basic (BLS) and advanced cardiac life support (ACLS) intervention has a negative influence over pre-hospital cardiac arrest outcomes. There were no survivors after prolonged delay in initiation of ACLS of 30 minutes or greater or total resuscitation and transport time of 90 min [21].

Seizure will cause a postictal state (an altered state of consciousness) in a person lasting from 5 min to 30 min [22]. Emergence from this period is often accompanied by amnesia or other memory defects which makes it impossible for the patient to ask for help or call 911.

All of the above medical emergencies indicate the critical role of in-time treatment; however, patients may lose consciousness accompanying with the disease, which increase the difficulty of asking for help. Moreover, disabled and elderly people with more physical difficulty are likely to fail to notify caregivers or family members.

Growing Health Care Standards

According to Sunyaev et al. [23], the future of health care system will be based on the communication between all information systems with the participants' information in an integrated treatment. Hence, the standards enabling interoperability between all information systems are vital. Interoperability, or adaptability, requires a set of standards for implemented technologies — the basis for data exchange and communication between participating applications [24].

On the other hand, as more effective and innovative treatments are developed, the standard of health care rises. Applying standards will help increase industry competition and therefore reduce costs. Standardization also enables medical information exchange between product suppliers. Errors will be reduced with standardization to provide safer healthcare services [23]. However, a federal government report argues the limitation that government regulation has over health care industry actually creates perverse incentives on competition and innovation. Price regulation could also hinder consumers' access to health care [25].

Besides the traditional health care, home care begins to enter the health care market as more and more elderly wish to 'age at home'. According to Bloomberg BusinessWeek [27], the regulators are catching up with the growing home care industry as U.S. Census data [26] shows that the number of companies providing home care services had doubled in the past decade. The home care companies that provide nonmedical services are targeting at $55 billion market as Americans over 65 and older will increase by 79 percent by the next two decade [26]. The concerns for regulations include whether or not nonmedical home care providers need 75 hours of training same with nursing home workers. Mistreatment risks are also under hot debate besides worker license. As services for seniors expand, home care companies are actively seeking for answers from regulators [27].

Rising Health Care Expenditures

Health care has always been an industry with high cost. From 1999 to 2009, health insurance premiums skyrocketed and more than doubled, outpacing the slow growth of families' income and inflation. Families are finding themselves paying much more out-of-pocket for health care services [28]. Small businesses were particularly hard hit. From 2009 to 2019, the health insurance premium for family will almost double in the next decade (see Fig. 2.1.2).

At the same time, health care expenditures are equivalent to a significant portion of the U.S.'s GDP. From Fig. 2.1.3, we can see health care expenditure accounted for 17.6% of total GDP in the year of 2009. By the year 2016, the Centers for Medicare and Medicaid Services (CMS) projects that health care spending will be nearly one-fifth of GDP (19.6 percent) [28].

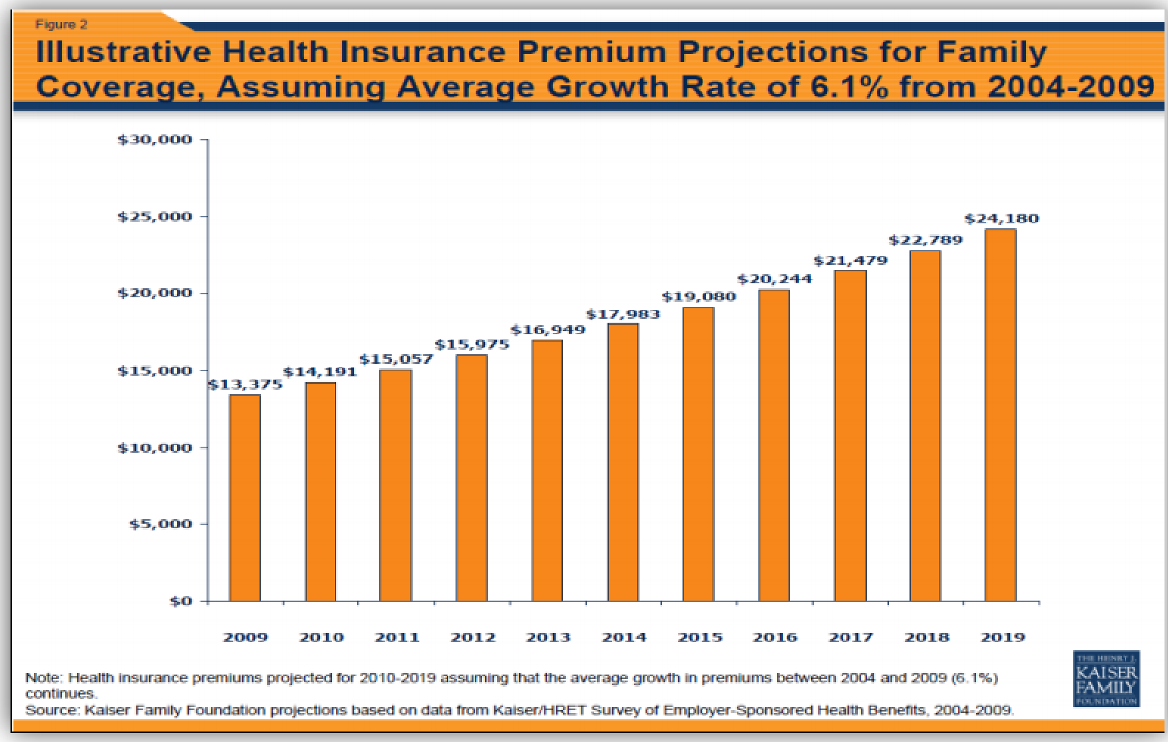


Figure 2.1.2 – Health Insurance Premium Projections for Family Coverage, 2009-2019, [14]

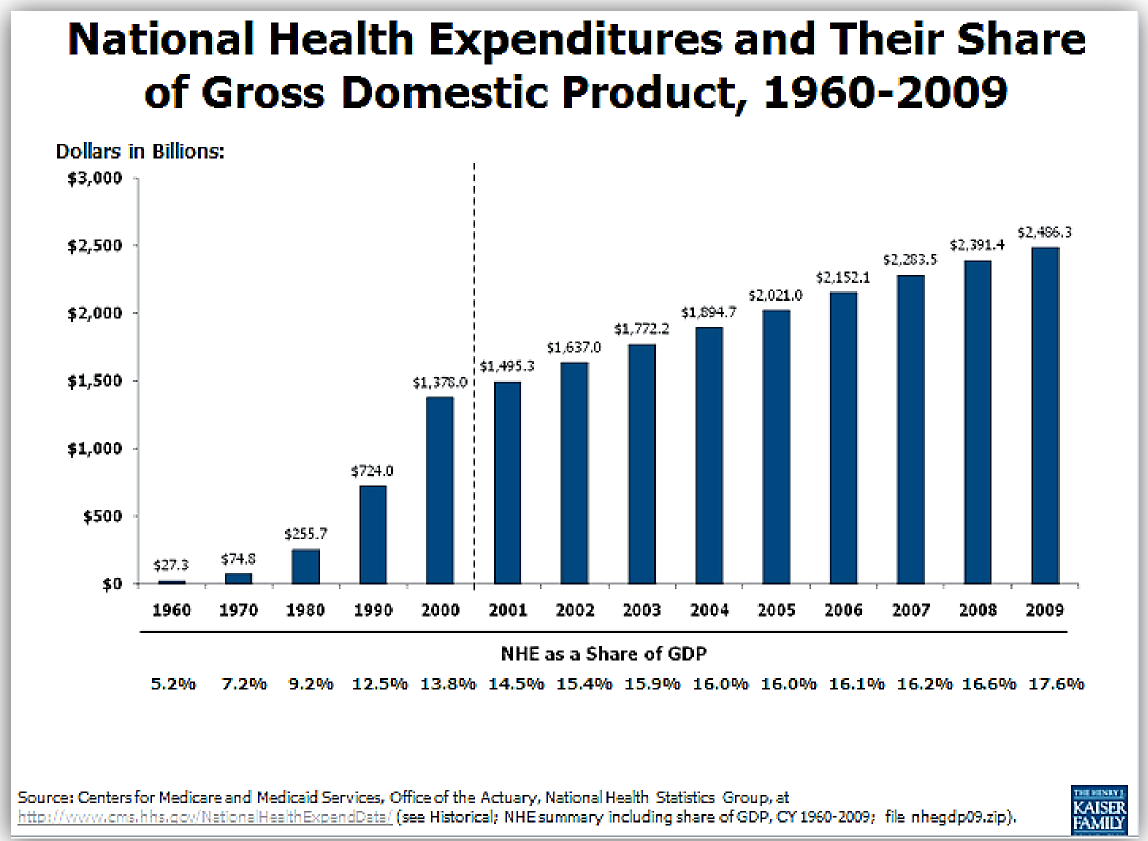


Figure 2.1.3 – National Health Expenditures and their share of GDP, 2009, [29]

Due to the trends of the rising health care expenditure, people are eager to seek for more affordable alternatives of adequate health care services. Robots, on the other hand, offer a solution to reduce the cost of clinical care, therefore providing people with easier access to appropriate health services [15].

Financial Restrictions

There are many factors affecting financial restrictions and this section will discuss the financial performance of American families with a focus on median level, population age 65 and household with a disability. Next, this section will review the information of current insurance programs in the U.S. The information overall will provide insights for the team to introduce the affordable robots to American families.

Not everyone in the United States is entitled to the same quality of care. According to U.S. Census Bureau, real median household income declined to $49,445 in 2010, a 2.3 percent decrease from 2009. Median income for age 65 years and older didn't change significantly but worker with disability have greatly decreased. In 2010, the median income of households with a disability was $25,550, an 8.5 percent decline from the previous year, compared with a median of $58,736 for those without a disability, a 2.1 percent decline from previous year.

Moreover, poverty rate increased 0.8 percent to 15.1 percent in 2010 and among people aged 18 to 64 without a disability, 12.5 percent and 22.0 million were in poverty. [1] The number of uninsured people increased to 49.9 million between the year 2009 and 2010, accounting for 16.3 percent. The economic crisis casted poverty spells of at least 2 months to 23.1 percent of the population [26]. What's even worse, around 7.3 percent of population was in poverty every month in 2009 [30].

[1] Note: According to the report, the results vary between different race groups. Poverty rates increased for non-Hispanic Whites, Blacks, and Hispanics but not significantly for Asians. While for health insurance, the rate and

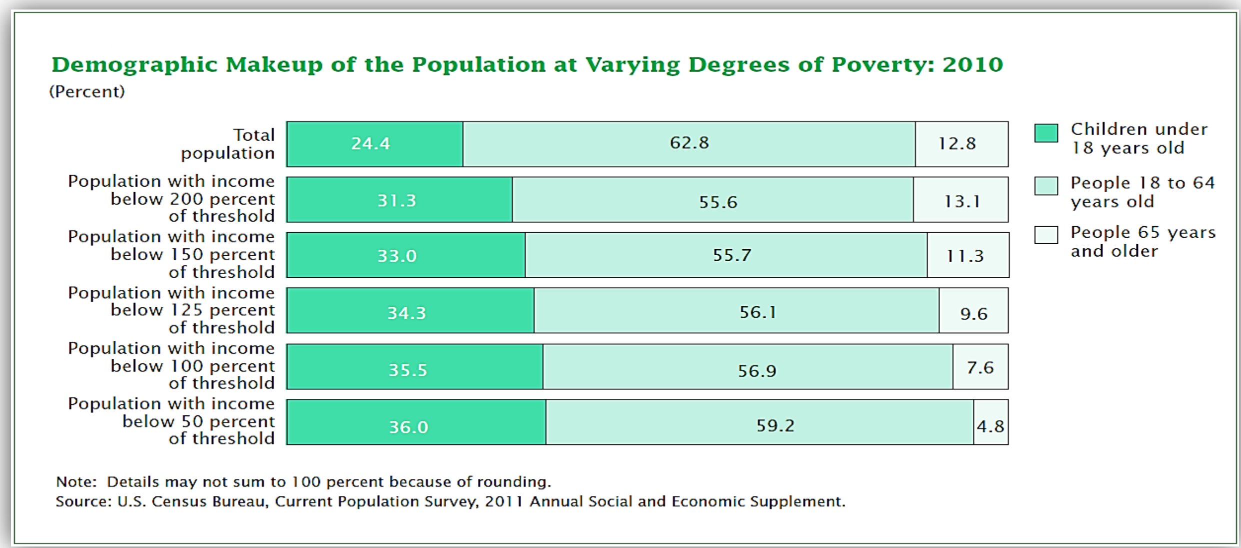


Figure 2.1.4 – Degrees of Poverty in 2010, [26]

Health insurance coverage in the Unites States is generally divided into two categories: private health insurance and government health insurance. Private health insurance is an employer or a union purchased plan [26].Government health insurance includes federal programs as Medicare, Medicaid, and military health care; the Children's Health Insurance Program (CHIP); and individual state health plans. Table 2.1.1 displays the main categories of insurance programs and the percentage of population they cover from 2009 to 2010.

Table 2.1.1 – Percentage of insurance coverage, [26]

Health insurance	Number of people enrolled	Percent of health care coverage	Percent of change from 09-10
Private health insurance	195.9 mil	64.0 %	0.5 % down
Government health insurance	95.0 mil	31.0 %	0.4 % up
Employment-based	169.3 mil	55.3 %	0.8 % down
Medicaid	48.6 mil	15.9 %	0.2 % up
Medicare	44.3 mil	14.5 %	0.2 % up

Other than people who have already been covered by qualified insurance program, there is approximately 16.3 percent of population uninsured. Fig. 2.1.5 showed the trends of growth for number uninsured and its rate from 1987 to 2010.

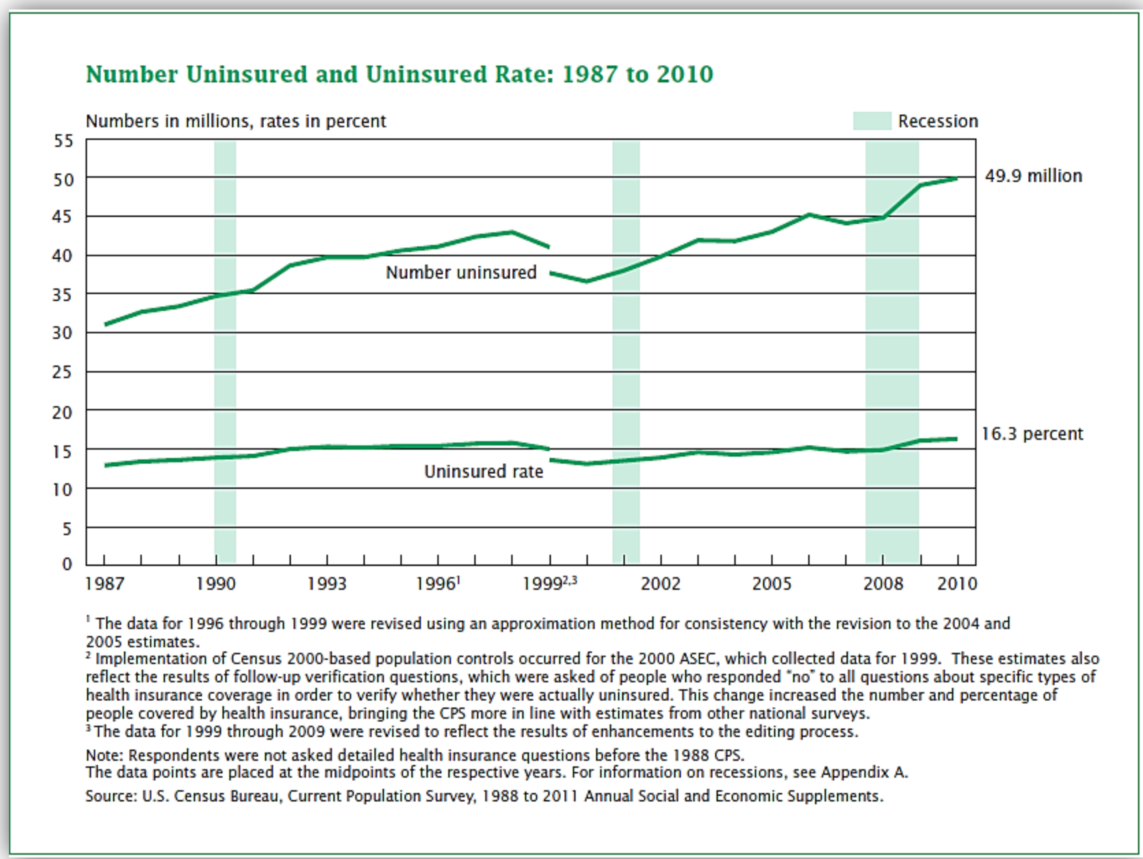


Figure 2.1.5 – Number uninsured and uninsured rate: 1987 to 2010, [26]

Fig. 2.1.6 examines the insurance enrollment information from age group 65 years and older for more information. The percent of enrollment in private insurance programs, including employment-based and direct purchase, totaled 98%. On the other hand, the percent for government insurance program, such as Medicaid, Medicare, military health care, totaled

93.5% in 2010. There was around 2% of the target population uncovered by any insurance programs or underreported[2]. More information can be accessed from Fig. 2.1.6.

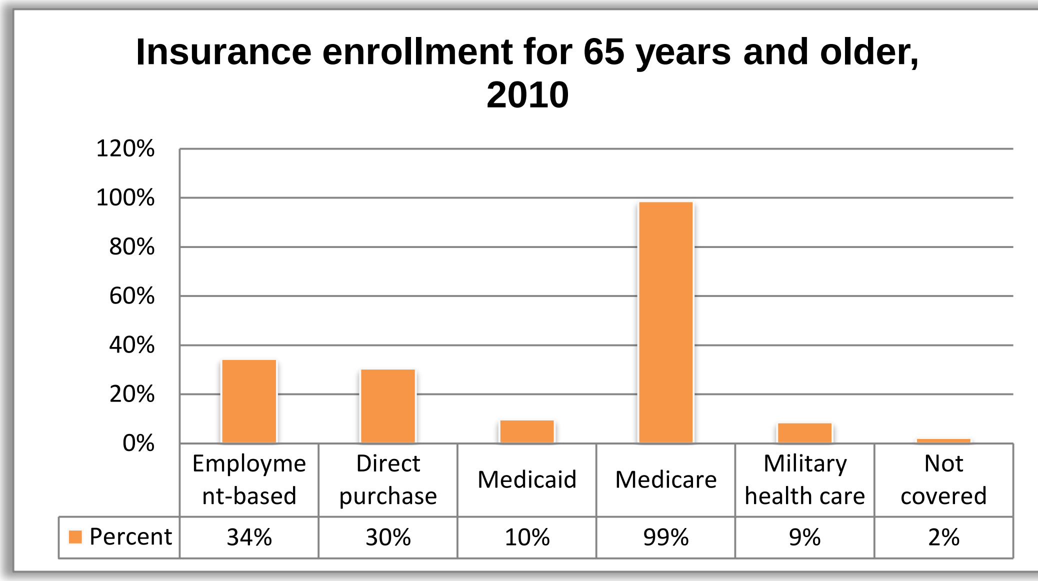


Figure 2.1.6 – Percent of insurance enrollment for 65 years and older in 2010, [31]

Income level is an important factor in financing health insurance and most restrictions come after the economic crisis. The income level directly determines the insurance coverage an enrollee chooses. As seen from Fig. 2.1.7 and 2.1.8, higher income level causes higher individual repayment amount and family repayment amount, higher premium and less cost sharing.

Medicare is a U.S. government public program that provides social insurance to Americans age 65 and older and younger people with disabilities. Medicare includes hospital, medical insurance which covers prescription drugs. The premium for Medicare enrollment ranges from $248 per month to $450 per month with other deductible and coinsurance [32]. According to Fig. 2.1.9, enrollment has gradually increased from the last decade and more growing can be forecasted.

[2] Note: As one person can enroll in several programs so the calculation is conducted with the real enrolled population divided by total target population. The sum of all percentage does not equal 100%.

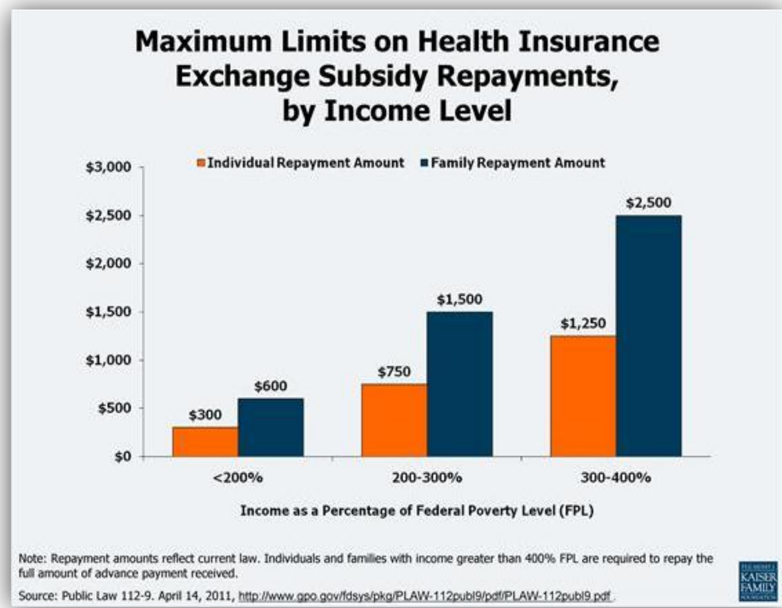
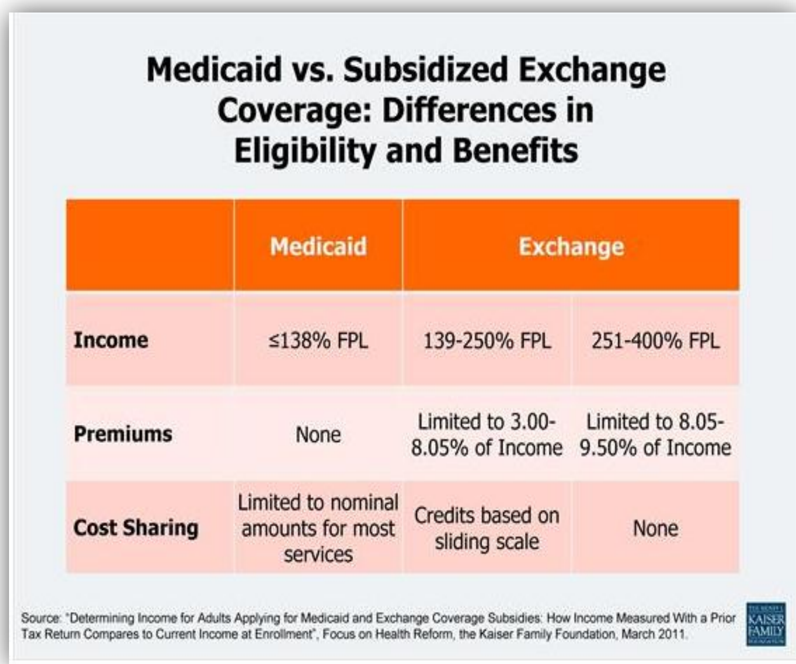


Figure 2.1.7 – Maximum Limits on Health Insurance by income level, 2011, [29]



Medicaid vs. Subsidized Exchange Coverage: Differences in Eligibility and Benefits

	Medicaid	Exchange	
Income	≤138% FPL	139-250% FPL	251-400% FPL
Premiums	None	Limited to 3.00-8.05% of Income	Limited to 8.05-9.50% of Income
Cost Sharing	Limited to nominal amounts for most services	Credits based on sliding scale	None

Source: "Determining Income for Adults Applying for Medicaid and Exchange Coverage Subsidies: How Income Measured With a Prior Tax Return Compares to Current Income at Enrollment", Focus on Health Reform, the Kaiser Family Foundation, March 2011.

Figure 2.1.8 – Medicaid vs. Subsidized exchange coverage, 2011, [29]

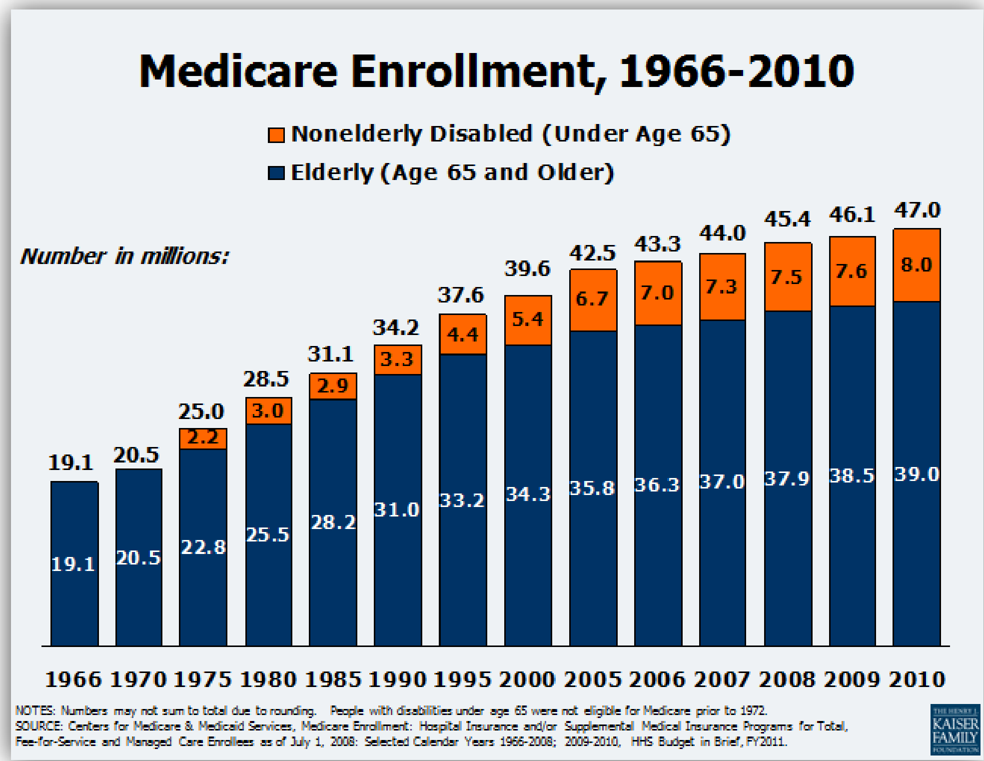


Figure 2.1.9 – Medicare enrollment, 2011, [29]

2.1.3 Technological Innovation and Reform in Smart Health Care

To discover the best opportunity to implement robotics in the health care industry, we can compare the supply of specific types of health services to the demand for those services. The supply of health care is a combination of health care personnel (such as doctors, nurses, technicians, and aides) and facilities (such as hospitals, outpatient clinics, and clinical laboratories) [33]. The demand is driven by our aging society and the increasing need for professional and personalized care. Since demand is outpacing supply in most areas of health care, there exist numerous opportunities for an effective and successful implementation of robotics. Technology in monitoring, assisting individual independence, and aiding patients with physical daily task is where technology innovation and reform should take place.

2.2 Overview of Users

This section first aims to investigate the types of users affected by shortcomings in health care, and identify possible sources among the traits of the users that may abet these shortcomings. It continues on to identify the most affected users, and investigate trends in that specific demographic.

2.2.1 Factors Determining Health Care Quality

There are many traits of or associated with the user that may influence the quality of health care people can expect to receive. Among these are income, age, gender, ethnicity, and level of education. Variances in these factors could affect the user's eligibility for health insurance, their purchasing power, or even their personal health needs.

Income

Income is one of the main factors that can determine the level of care a user may receive. In most cases, a person's income stems directly from their level of education, gender, race, or age. A higher income means a greater ability to invest in expensive medical practices and medicines—a user's purchasing power. A less direct, but certainly very common, way income may affect a user's expected level of care is through insurance. High-paying jobs often provide good insurance coverage, but even without this benefit, those with more money to spend have a wider array of insurance plans available to them.

Those with a Bachelor's degree or more have significantly higher earnings ($93 thousand compared to $56 thousand with an Associate degree), increasing both their purchasing power and access to insurance. There also exists a lesser but still significant disparity of income between genders and races; females earn about $20 thousand less than males (also seen in Fig. 2.2.1), and whites and Asians tend to earn $10-15 thousand more than blacks and Hispanics [34]. Other earnings for varying education levels of both genders can be seen in the Fig. 2.2.2.

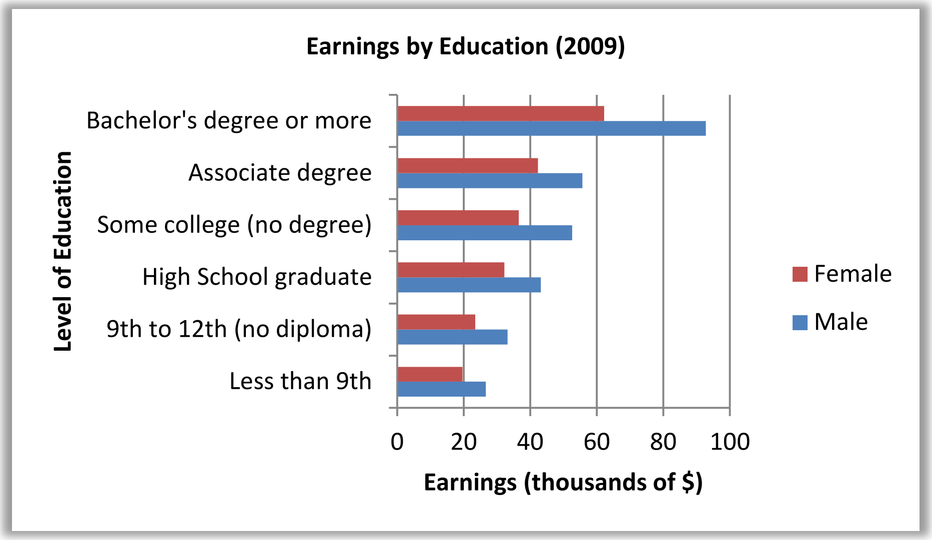


Figure 2.2.1 – Adult Earnings in the U.S. by Education Level & Gender, [34].

Age also plays an important role in the amount of spending power users have. According to the 2007 Survey of Consumer Finances, those families with a head ages 65-74 have the highest average new worth (approximately $1 million) and the second highest median net worth (approximately $240,000), as seen in Fig. 2.2.2. This same survey indicates that those who are retired still manage to have the second-highest net worth ($128,800 median, $477,600 average) [35].

Age Range (head of family)	Median Net Worth	Average Net Worth
Less than 35	$11,800	$106,000
35 - 44	$86,600	$325,600
45 - 54	$182,500	$661,200
55 - 64	$253,700	$935,800
65 - 74	$239,400	$1,015,200
75 or more	$213,500	$638,200

Figure 2.2.2 – Net Worth of U.S Families by Age of Head of Household [35]

Age

Currently, the elderly population (ages 65 and over) makes up approximately 13% of the U.S. population [36]. The proportion of the elderly, however, is rapidly increasing, as seen in Figure 2.2.3. Not only is the Baby Boomer generation beginning to reach the elderly age group, but the proportion of people aged 60 and over is expected to double from 2000 to 2050 [37].

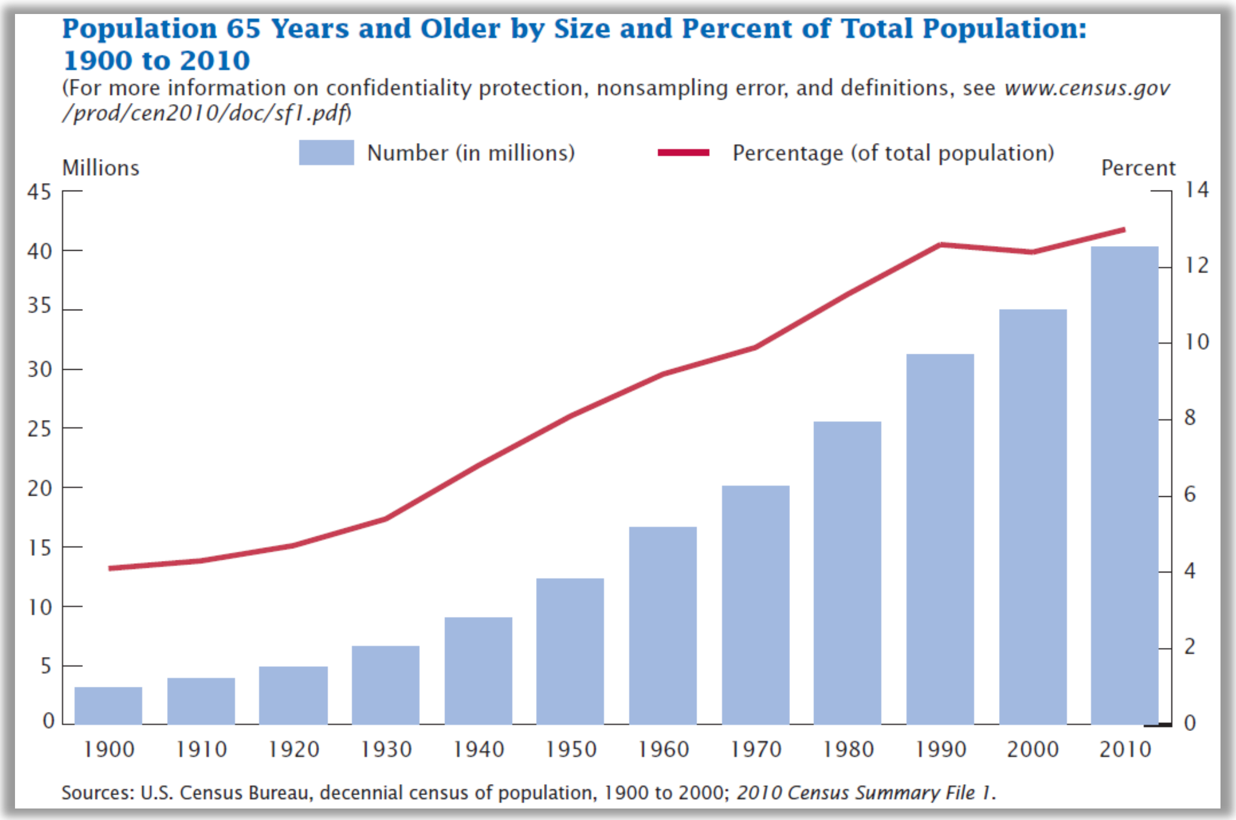


Figure 2.2.3 – Growing elderly population of the U.S. [36], [53]

The growing size is not the only reason to be interested in this group from a healthcare perspective; many of the elderly need very involved medical care – certainly more than those in younger age ranges. Healthcare for the elderly may consist of a wide range of tasks: physical assistance, monitoring, providing reminders, or social interaction for example. Many elderly suffer from impaired mobility, or lack a means of transportation altogether, which can certainly affect the level of care they receive. About 25% of those over 75 are mobility impaired [38], and considering the quickly-growing segment of the elderly, this mobility impaired segment of the population is likely to expand.

Additionally, those 65 and older may not have access to internet, or may not use the internet, causing them to miss out on a vast amount of information pertaining to healthcare services and healthy living. In fact, 26% of those age 65 and over don't have home broadband access, and only 38% use the internet at all [39].

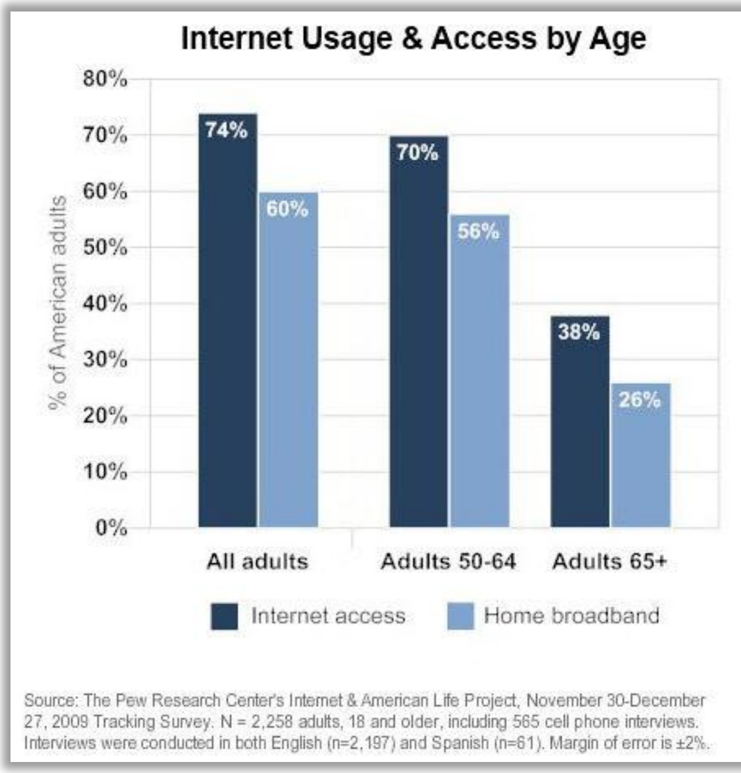


Figure 2.2.4 – Internet Usage & Access by Age [39]

Gender

As previously discussed in the Income section, it is not uncommon for females to make significantly less money than their male equivalents, with differences ranging up to $30 thousand [34]. This lower income means they are disadvantaged when it comes to purchasing both healthcare services and health insurance. Unfortunately, women typically pay more when it comes to health insurance, sometimes as much as 40% more than men [40]. This is at least partially due to the higher healthcare costs associated with females because of pregnancy and childbirth [41]. Despite the higher cost of insurance, females are generally more likely to have health insurance; 86% of women, versus 74% of men [42]. This fact is quite surprising, considering the higher cost and lower availability of health insurance for women. One cause of this could be associated with the psychological difference between men and women: females are usually more likely to admit a need for personal help than men.

Ethnicity

In addition to its previously-mentioned influence on income, a user's race can have distinct effects on the degree of healthcare they can expect to receive. For some races, communication with medical providers who only speak English can be problematic. If these patients are not proficient enough in English, they may not be able to receive the level of care they need or deserve, or they may even be victims of malpractice [43]. Furthermore, racial minorities in the U.S. are more likely to have limited health insurance plans (if they have health insurance at all), restricting covered services and available healthcare providers [44]. Because of both their limited income and insurance, certain races are far less likely to be provided with quality healthcare.

Education Level

As mentioned in the *Income* section earlier, education level has a massive influence on the earnings and therefore the purchasing power and insurance eligibility of individuals. High levels of education can lead to jobs that either provide healthcare insurance or provide the money needed to invest in healthcare services.

Outside of the income and insurance factors, education level can have a more direct effect on healthcare received by individuals. Some under-educated patients may lack understanding of good health practices and ways of attaining health services [45].

2.2.2 User Characteristics

A user's willingness to accept and adapt to both evolving technology and health care practices is largely dictated by their characteristics. Their familiarity with technology, medical conditions, attitudes towards health care, and even developmental environments all play a part in defining the user affected most by the shortcomings of health care. Further investigating these characteristics gives a better idea of the user at hand, and how to cater to and design for this specific demographic.

Familiarity with Technology

Ensuring that the user is familiar with the device in front of them is a major challenge for any technology designer. In this case, designing for the elderly calls for a simplified, passive approach to keep the user comfortable and give them a feeling of control. Previous experience with or interest in popular technology such as cell phones, the internet, and personal computers is a major plus when interacting with any new form of technology.

As stated earlier, only 38% of the elderly population in the U.S. uses the internet, compared to an average of 74% for all adults [39]. Furthermore, of people 50 and over, just 4% use smartphones, and 4% use mobile phones. Continuing with this generous sample size, 40% of those 50 and older prefer news from newspapers & magazines [46]. It is obvious that many members of the older U.S. population lack familiarity and experience with the current era of information technology, which could prove troublesome when trying to integrate the rapidly growing fields of healthcare and information technology into their daily lives.

Willingness to Accept New Technologies

As technology becomes more widely spread, and the increasing elderly population will shift to those who are more familiar with social and information technology, namely the baby boomers (those aged 46-64). This shift will be beneficial for the smart technology market, as the current elderly generation is not very tech-savvy by comparison. Robert DiLallo of Grandparent Marketing Group states this idea very well: "People who are 65 and older were at the tail end of their careers when the real tech revolution began" [47].

Over the last 10 years, the number of baby boomers who have adopted daily internet use into their lives has nearly tripled and about 82% own cell phones [47]. By the time this group becomes the elderly demographic, their adoption rates of social and information technology should be nearly as high as the younger generations'. This is good news for the integration and expansion of smart technology in healthcare, as social and information technology lend themselves to this integration in many forms.

In addition, many of the current-day elderly were raised in a time with far less interactive technology than today and as such may have vastly different social preconceptions than today's younger population. The elderly today were born between the Great Depression and the World War II eras (1920s - 1940s). Since their childhood, this generation has experienced the evolution of communication technology all the way from the radio and early television to the internet and cell phones. Especially in recent years with the exponential increase of technology, it is believable that the available technology market is growing too fast for the elderly to keep up. Staying on the forefront of technology requires not only time but understanding that those age 65 and older do not always have. For these reasons, apprehension towards new technology is common and quite understandable.

Spending Habits

Among the elderly age 65 and over, the most money is generally spent on health services. This stresses the idea that many of the elderly are in need of cheaper and more readily-available healthcare and health services. One segment from The 2010 Bundle Report (shown in Fig. 2.2.5) shows that the elderly spend over $9000 on annual healthcare expenses, the highest of all the age groups in the United States.

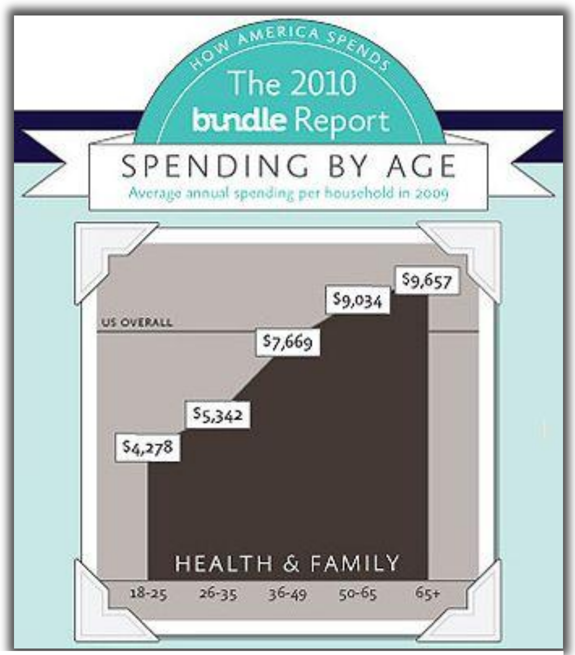


Figure 2.2.5 – Health Spending by Age, [48]

Spending on technology is also on the rise for the (early) elderly age group. Forrester Research's annual benchmark study states that the baby-boomer segment of the population already spends the most on consumer technology of any demographic [47].

Need/Condition

Caring for the elderly currently requires significant resources, and is only going to become more expensive as the size of the elderly population increases. At TEDMED 2009, Colin Angle of iRobot discussed the current trends in the growing size of the elderly and their medical needs. Even now, 22% of people under the age of 65 dedicate as much as 6 hours every day to directly caring for someone over the age of 65. Furthermore, paying for nursing home assistance can cost over $10 thousand per month [49].

The users' needs are directly dependent on their current medical condition. On a basic level, the users' medical conditions can be divided into three main categories: physical, mental, and social. Each one of these categories calls for distinctly different health services, and all could certainly use more support in the healthcare industry.

Physical conditions may include, but are not limited to: rehabilitation (after surgery/injury) or assistance (with walking, sitting/standing, etc.). Some users with mental disabilities may respond well to therapy or interaction, and are especially important to give reminders to and monitor. Partially associated with the mental category, social aid and interaction is an important aspect of healthcare. Helping the elderly patient maintain a fresh mind by encouraging interaction and communication may prevent the onset of diseases like dementia, or may simply keep the patient in good spirits.

Attitude Towards Healthcare

An individual's attitude towards healthcare may vary greatly depending on their age, understanding of medical practices, or a number of other factors. The user's attitude will certainly influence their willingness to accept certain healthcare services, especially if it will mean a change in their lifestyle. In fact, more than 75% of the elderly prefer to "age in place" [49], meaning they hope to remain independent enough to remain in their current living situation. This is understandable, as the vast majority of the time an elderly person makes a lifestyle change; it is because of their dwindling independence. Therefore, is it not surprising that some patients age 65 and over are apprehensive of giving up any semblance of independence to healthcare services.

Developmental Environment

Where the user lives and grows up greatly influences their culture and perception of the world. Experiences with their community and even the user's religion may alter their view of technology. Especially with forms of technology like robots, which in some cases strive to imitate life, there are sure to be preconceived notions about their functionality, purpose, and structure. Because of this, users in some locations may be less accepting of a home healthcare robot, a factor that should be considered when designing for large demographics.

A good illustration of the differences in perception, function, and structure of robots by location can be seen when comparing the United States, Korea, and Japan. In both the U.S. and Korea, robots are seen as professional assistants; in the U.S., they are usually used for dangerous or repetitive jobs, and in Korea they my serve in the emergency medical care field. In Japan, however, there is a heavy emphasis on human- or animal-like robots, which are used largely for casual social purposes. Continuing the trend, the U.S. and Korea have a large share of robots that are in or a product of research and development, while Japan has a surprising emphasis on the commercialization of robots [50].

2.3 Definition of Robotics

This section presents the team's definition of a robot in addition to a classification system that will be used throughout the project to categorize and evaluate robots in the health care industry.

In developing accurate user requirements for a health care robot, it is helpful to evaluate existing robots that are in development and/or have reached the consumer market in the health care field. In order to obtain meaningful information from such an evaluation, the project team has decided that a taxonomy of robotics is an appropriate tool to use, as a taxonomy could potentially help to determine the defining characteristics of a successful health care robot. However, upon researching existing taxonomies, it was found that most attempt to categorize the entire spectrum of robotics, something that our research does not necessarily need to consider. Instead, the team has decided to develop our own taxonomy of robotics, utilizing some ideas from the taxonomies researched to cater to the projects specific concerns and goals. Before development of the taxonomy could begin, however, robotics had to be defined in general. Drawing on a definition proposed by Boni et al. [51], the following definition was developed: a robot is a machine that is capable of obtaining data from its environment by means of sensors, processing the data at least to some extent, and reacting to this data by means of actuators (see Fig. 2.3.1). However, the team's definition of actuation differs from theirs: The team's idea of activity is not limited to mechatronic motion, but rather encompasses any possible activity that may be carried out, such as emitting a sound or projecting an image in addition to mechatronic motion. By this definition, a wide variety of machines may be considered robots, from automatic doors used in super markets to the da Vinci surgical robot.

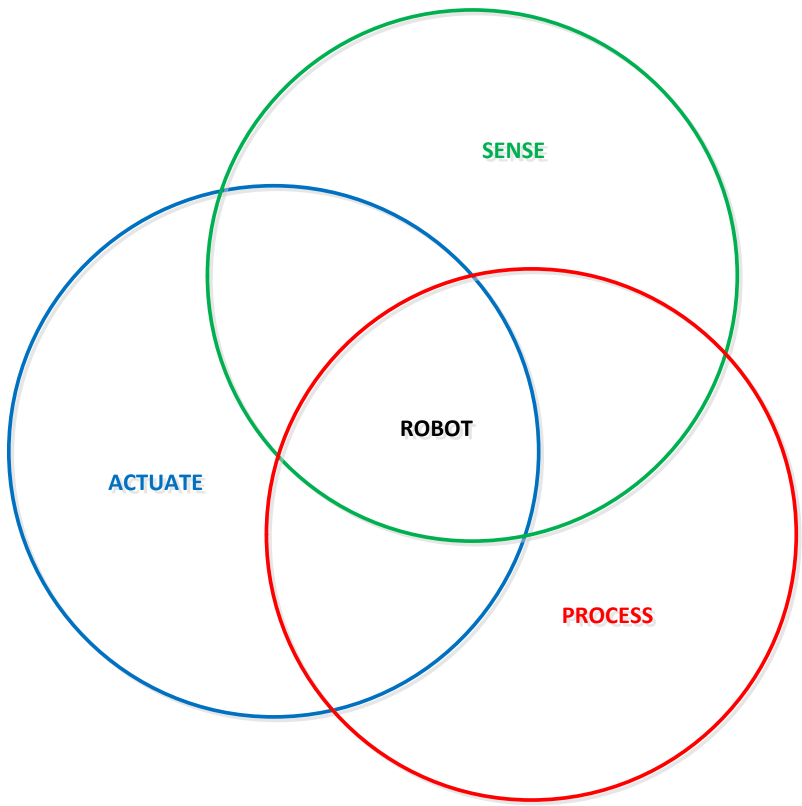


Figure 2.3.1 – Definition of a Robot [51]

2.4 Current Health Care Technology

In this section, we will discuss several focus areas of current technology and ongoing research in robotics within the health care industry. By navigating current technologies and innovations, we can categorize the industry in order to clarify the purpose of applied technologies and determine how or where else they may be applied. This process will help us discover what types of technologies are available and may be utilized in a health care robot, how to apply them to perform a specific function and satisfy the user(s), and where these technologies are headed as far as research and development goes. Finally, we will introduce several technologies that have not been well accepted by the public, as well as a few technologies currently under development. Overall, the contents of this chapter will compile a list of health care relevant technologies that may be applied in a conceptual design of a smart health care robot.

2.4.1 Motivation of Health Care Industry

In the past few decades, the role of robotics in the health care industry has increased tremendously. The heavy application of robotics in health care and medicine has been driven by the exploding demand for health care. Technology has also had a major role in the growth of the national health care expenditure: Spending on health care research and equipment has nearly tripled since 1990 [52]. There are many challenges to build a health care robot, since this revolution requires new concepts, hardly considered before the boom of robotics, such as interactive, user-friendly, and “smart.” In fact, IRobot declared a new health care business division in 2009. The company is still having difficulty getting a single product to market, however. The most recent health care related patent from IRobot was published in 2010. There are many more brilliant robots and intelligent systems in the market which we will look through in this chapter.

There are various reasons why health care has turned to robotics, such as an increasing elderly population [53], worker shortages [54], [55] and increasing health care expenditures. Since one of the first patient assistance systems was introduced to the world [56] robotics technologies have been remarkably developed in numerous industries such as nuclear power, military, medicine, and health care (the first surgical robot was produced a decade earlier [57]. These innovations in robotics significantly improved the health care industry and made it much more accessible to the general public. The progress we are seeing is driven by the health care needs of our society and generates a synergizing effect. The overall quality of health care increases as the technology associated with it develops. As the quality of health care technology improves, the applications of the technology become much more specific, and this results in specific fields of health care robotics. These recently-born fields can be classified into several different, but related fields. Of course, each field requires focus in a different area of robotic technology.

2.4.2 Clinical Applications

Where in the health care industry is robotics applied most commonly? What purpose does it serve? Does it serve this purpose well? Are patients and health care personnel satisfied with its performance? These questions are important to ask when considering possible applications of robotics in the future. There are many possible applications for robotics within health care, but robots are currently used mostly in clinical applications, such as surgery. Surgical robots, for example, have been around for more than thirty years [57]. This is not to say, however, that the technology has not been improved since its implementation. Surgical robots have become extremely sophisticated, even allowing surgeons to operate them from thousands of miles away. The da Vinci surgical robot system is a good example of the progress surgical robotics has made since its conception.

da Vinci System

One of the most well-known surgical robots, the da Vinci robot, is a typical example of robot surgery. There have been roughly 3000 peer-reviewed studies published demonstrating the clinical effectiveness of the da Vinci surgery system [58].

In addition, more than 800 hospitals in the United States and Europe use the robot in various types of surgery [59]. This system is undergoing considerable research and has been successfully applied in general surgery, cardiothoracic surgery, urology, gynecology, and possibly otolaryngology [60]. The da Vinci system is made up of three primary components (many other applications can be added on): a surgical cart, vision cart, and surgeon console (see Fig. 2.4.1).

Figure 2.4.1 – Three primary components of the da Vinci system:

Surgical cart (most right), vision cart (center arm), and surgeon console (center-left).

The surgical cart is a robotic manipulator with three arms: one camera arm with a 12mm stereoscopic laparoscope and two others arms that hold 8mm instruments. One interesting technology applied here is the EndoWrist Instruments technology. Tiny computer-enhanced mechanical wrists allow a full 7 degrees of freedom at the instrument tips. Instrument tips are aligned with the instrument controllers electronically to provide optimal hand-eye orientation and natural operative capability [61]. This innovative wrist was inspired from the Black Falcon of MIT [62]. Overall visualization of operation is performed by the vision cart, which consist of two three-chip cameras mounted within one integrated and three dimensional 12mm stereo endoscope with two separate optical channels. The operative images are transmitted to a high-resolution binocular display at the surgeon console. The surgeon can see the operation in a 3-D (can be changed into 2-D) stereoscopic illustration on the console. Then he maneuvers robotic manipulators, which allow him to control the robotic arms and cameras. This setup achieves more precise and accurate manipulations of instruments than those that can be achieved from conventional endoscopic surgery.

Even though it has been more than 25 years since the first introduction of minimally invasive surgery techniques, fewer than 3% of the colectomies in the United States were performed with the laparoscopic method during the year 2000 [63]. However, the public was aware at the time that robotic surgery was possible. For some specific surgeries, considering many factors including post-surgical recovery time and the limitations human joints presented to surgeons, these robots do perform excellently, even better than surgeons do in these specific applications. It is impressive that a machine is capable of reproducing human activity more precisely than the human can. The da Vinci system clearly illustrates the current state of surgical robotics.

2.4.3 Non-clinical Applications

Today, robots are capable of not only surgery, but also various other jobs in the field of health care, such as rehabilitating patients, providing/supporting professional care, and providing diagnostic assistance. In this section, we will focus more on the non-clinical roles of robotics in smart health care systems (see Fig. 2.4.2).

Figure 2.4.2 is a breakdown of health care technologies, modifying the existing model from the European Commission [64]. Non-clinical applications in health care can be classified by focusing on four major applications: extended professional care, preventive therapies and diagnosis, assistance, and rehabilitation. By introducing robots used in each of these applications, it will be easier to understand how current technologies were developed.

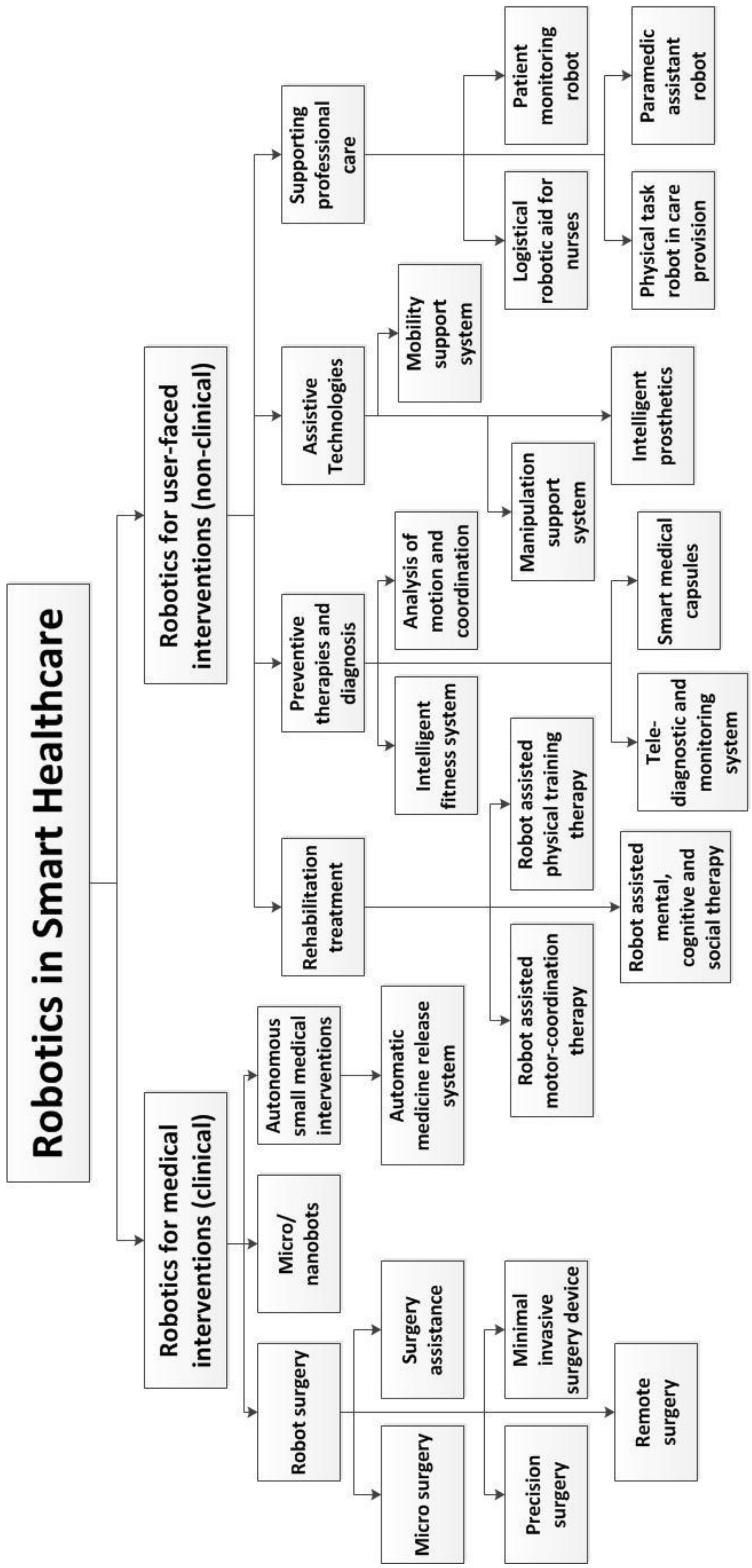


Figure 2.4.2 – Breakdown of Robotics in Smart Health Care [64]

Rehabilitation Therapy – The "Paro" Robot

Rehabilitation therapy is an important aspect of health care; one important focus is the social interaction between rehabilitation therapists and their patients. A good example among the many commercially available therapeutic social robots would be the seal robot, Paro (see Fig. 2.4.3). This robot is intended to improve the health of the user by providing him/her with social interaction. Paro shows how increased social contact and networking affects the recovery cycle and psychological stability of humans.

Figure 2.4.3 – Paro, a companionship and therapy robot.

The robot was inspired from the fact that interacting with animals is emotionally beneficial to mankind. The influence of social engagement on cognitive decline, particularly among elderly people, has been examined [65]. Paro is intended to counter the degenerative effects of lacking social interaction. The first interesting attribute of this robot is appearance. To make the robot seem inviting and friendly, the developers of the robot decided to model it after a baby harp seal covered with pure white fur. Paro contains tactile receptors under its "skin" capable of recognizing and measuring physical contact. The appearance of Paro can have a very positive effect on the acceptance of the robot by the users, particularly children and elderly who don't require highly technical functionality [66], [67]. This 2.8kg (6.17lb) seal robot has four primary senses: sight (light sensor), hearing (voice recognition system with direction determination), balance, and tactile. There are more user-friendly features on Paro, such as a mechatronic neck, eyelids, and tail. One relatively sophisticated technology applied in Paro is a behavior generation system [68]. This software platform is made up of two layers of processes: a proactive and reactive layer. The system can generate a total of three different types of behavior. It is like a state-machine. Proactive behavior consists of a planning, generating, and memory layer. This proactive process mimics a real seal's posture and movements. These change by stimuli from the users. The memory layer is particularly interesting and innovative. Long term memory makes it possible to "remember" and repeat a previous pattern of movement. This feature lets Paro adjust to the preferred behavior of the user. In addition, Paro can memorize frequently articulated words, like its given name. By repeating a certain word in natural interaction, the user can give Paro a new name and receive feedback as a series of movements.

Paro is an innovative application of various technologies with the purpose of helping facilitate the mental and cognitive recovery and rehabilitation of elderly patients by means of social interaction. There are typically two kinds of elderly care robots. One is rehabilitation-oriented and the other is socially-oriented. It is difficult to satisfy both of these needs [69]. Paro, however, serves both purposes, making it more appealing to consumers. Another fascinating feature of Paro is that it can actually interact with users in multiple dimensions: the robot has many different reactive behaviors with high-quality features like long-term memory. Paro is a good example of how software can provide significant functionality with limited sensing and actuating components.

2.4.4 Preventive Therapies and Diagnosis – Intelligent Fitness System

The second largest branch of smart health care is preventive therapies and diagnosis. This area covers independent diagnostic methods such as robotized endoscope and tele-operation systems which independently monitor patients and preventive technologies such as intelligent fitness system and multiple objects motion/sound recognition system.

The concept of intelligent fitness system [70] is recently introduced to smart health care industry. This system differs from the conventional exercise/fitness program which generates and updates the user's body condition in a period of two weeks to several months. It is difficult to keep a regular schedule and a good health condition since many people have schedules that vary daily. After surgery, people often need to learn new exercise methods due to limitations caused by the surgery. These unpredictable and irregular events do not reflect what the user's body needs and this problem can lead inappropriate exercise methods once the interval becomes longer.

This ubiquitous and self-adaptive system consists of a sensor interface, user interface, interface manager, exercise model manager, and calorie manager. In addition, this system has an exercise database (see Fig. 2.4.4). This system uses an exercise optimization algorithm to maximize the cost-effectiveness of exercise as a concept of a feedback control loop which engineers the system explicitly. It can also accept inputs interactively [71]. User identification, physical check-up, going through exercise history, and sensing current user status are specific technologies used in this system.

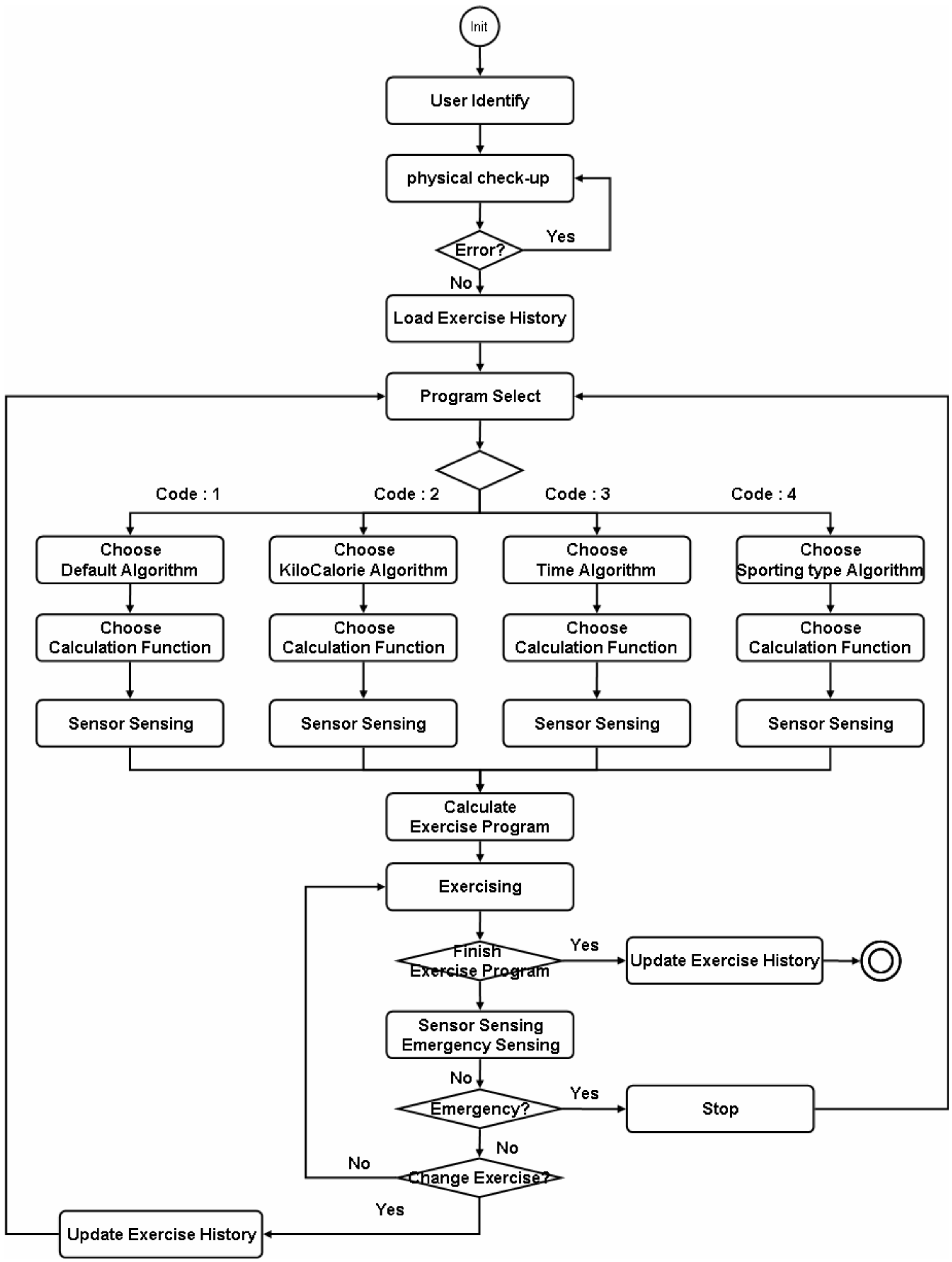


Figure 2.4.4 – Workflow of Intelligent Fitness Guide [70]

2.4.5 Robotic Assistance Technology – Intelligent Prosthetics

Another important field of health care is robotized assistance. There are many robotized assistants, including intelligent prosthetics, robotized transportation system, and manipulation assistance. A robotized artificial ankle is a good example of this kind of technology (See Fig. 2.4.5) [72]. This mechanical ankle senses which phase of stride the ankle is on, and manipulates the angle of the bottom plates with springs. The stored energy in the spring releases to the next phase of walking which saves between 14 and 23% of the energy spent using conventional prosthesis.

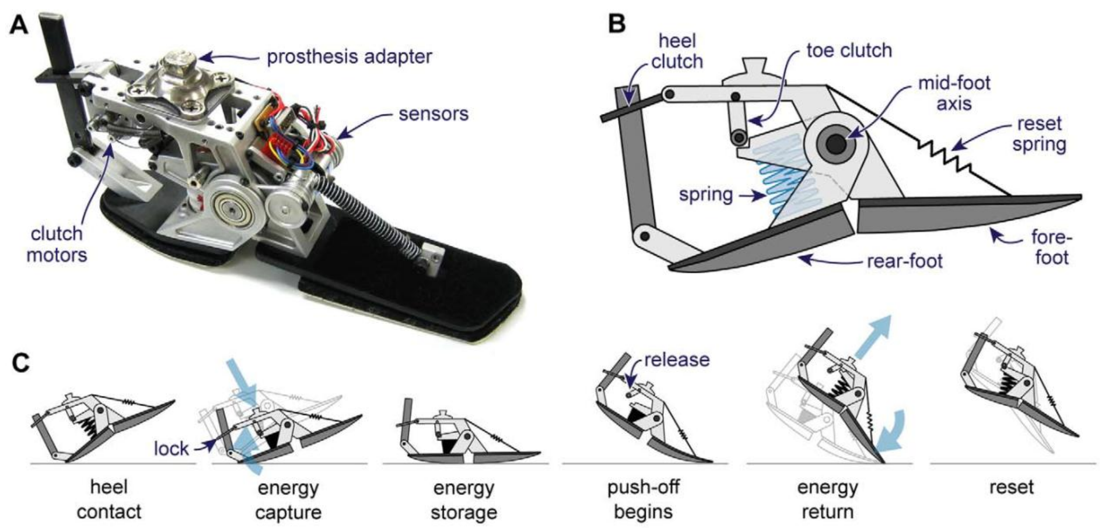


Figure 2.4.5 – Energy Recycling Foot [72]

2.4.6 Discussion

So far we looked various examples of both clinical and non-clinical applications of robotics. Based on the robots introduced above, it is clear that there are different essential technologies applied on each robot in different type of application and health care field. The distinguished technologies can be organized as 'tree', a good example of the technology tree is shown below (See Figure 2.4.6). Original version of the tree is unnecessarily complicated; the team re-organized the original key technology tree by profiling the robots above and simplifying unrelated technologies. We also used the Figure 2.4.2 as reference to determine big branches of technology tree since different area of healthcare robotics requires different functions to satisfy user(s). In this way we can easily see what types of technologies are used in different types of applications and deliver various required functions.

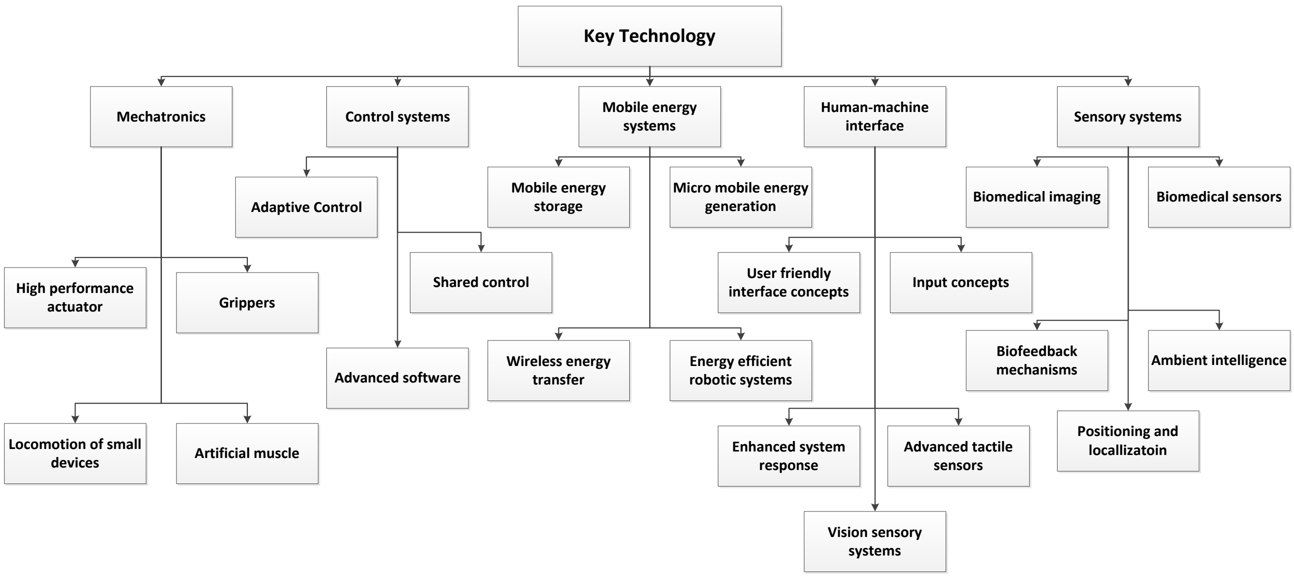


Figure 2.4.6 – Key Technology Tree [64]

3 Methodology

Various objectives were laid out earlier in the paper: reviewing existing health care robotics, creating a taxonomy of health care robots, identifying user needs and preferences, and developing a set of user requirements and recommendations for a personal health care robot. In order to fulfill these objectives, the team performed the methods discussed in this chapter to gain a better understanding of the health care industry, robotics in that industry, and potential users' acceptance of such robotics.

3.1 Literature Review

The following sections describe the research methods and reasoning behind the literature reviews conducted on health care, the elderly demographic, health care applications for robots, and robot taxonomies.

3.1.1 Health Care & User Overview

This section presents the research methods and reasoning behind the health care and user literature review. The review is intended to identify an area of health care that would be improved by the implementation of robotics and to define the users associated with that particular area.

Motivation

Since the smart health care industry has been determined as the focus area for this project, determining the ideal market for a potential health care robot is synonymous with determining the area of health care with the greatest need for technological innovation or reform. Defining a specific subfield is not particularly easy however, as health care is a highly interconnected industry with many overlapping parts. Thus, rather than isolating separate subfields within health care, it is more effective to determine the shortcomings of health care industry and the technology associated with it in general. With the flaws of the current health care system well defined, it is possible to determine who is most greatly affected by these flaws (potential users) and if the implementation of robotics can address those flaws.

Objectives

The main purpose of this research was to identify an area of health care that would benefit from the implementation of robotics of any kind, and to provide some insight into the needs, expectations, wants, understanding of technology, opinion of technology, etc. of the patient demographic associated with the aforementioned health care field.

Research Methodology

To define specific flaws and in turn the need for innovation within health care, several factors had to be considered: expenditures, quality of care, patient quality of life, ratio of patients to health care personnel, quality and cost of human resources, quality and cost of other resources, as well as demographic statistics. To obtain this information, heavy statistical research of the economics of health care was necessary. Key words searched on Google Scholar and IEEE Xplore included the economics of health care, health care shortage, elderly health care costs, health care costs, Medicare, Medicaid, hospital overcrowding, paramedic response time, hospitalization statistics, demographic breakdown of US population, population growth rate by age, health insurance policies, and health care salary. We focused only on recent works (post-2000, post-2005 for demographic information) related to the factors mentioned previously. The results were not limited to solely American articles; an idea of how health care systems function in other countries is desired to gain a better perspective of the issues at hand in the US.

With the information collected from the search conducted above, it could be determined who is least favored by the current health care system. This population is synonymous with the potential users of the team's ultimately proposed health care robot. Simply identifying the potential users was not sufficient, however, and further research had to be conducted to define the characteristics of the user. The main characteristics to identify were age, medical condition, living arrangement, and income, but a deeper understanding was still necessary: factors like the users' spending habits, media exposure, familiarity with technology, acceptance of technology, (in)dependence, ideological predispositions, etc. had to be considered to develop a thorough definition of our intended users.

To develop this definition, research about the users' demographic was to be conducted. The following terms related to our selected users using the resources mentioned previously were searched: American spending trends/habits, internet use among the elderly, cell phone use among the elderly, acceptance of smart phones, eldercare robots, assisted-living robots, and robot acceptance in America. The goal of this research was to get an idea of how comfortable the elderly feel with various types of technology, including robots, as well as to get a sense of how much value these technologies have present to them. Understanding the average financial restrictions of the elderly will also be important when developing the requirements of a health care robot.

3.1.2 Definition & Taxonomy

This section presents the research methods and reasoning behind the systematic literature review of robot taxonomies. The review was intended to define the term "robot" and to provide an understanding of existing taxonomies related to robotics and their categorization methods.

Motivation

The team decided that a classification system, or taxonomy, for robots would help organize existing technologies and identify the relationships between the various components of said robot, its user(s), and its success as a marketable product. By studying these relationships, the team hopes to identify the optimum attributes of a health care robot, taking into consideration the technology applied in the robot itself and its user(s)' needs and expectations. However, an appropriate taxonomy must be applied in order to provide the desired information. In order to locate an appropriate classification system, a systematic literature review of existing taxonomies was conducted.

Definition of a Robot

The first step of constructing a taxonomy of robots is to define what a robot is. There are hundreds of interpretations and definitions for this term, as well as countless products that are considered to be "robots," so the team had to sift through robotics-related literature in order to develop a legitimate definition that is appropriate for our project. A simple definition was preferable, as it would allow for more flexibility when ultimately determining the requirements of a health care robot. We also decided that a classification system was required to organize existing robotic technologies and identify the most appropriate components of a robot intended for a specific application, in this case elder care.

Objective

This review will have ideally provided a previously proposed taxonomy that is relevant to this project, but because no such taxonomy exists, the team had to develop a unique classification system drawing from the reviewed taxonomies.

Research Methodology

The literature search was conducted on Google Scholar. Only journal articles containing the words "taxonomy" and either "robot" or "robotic" published no earlier than 1996 were considered. This search query was intended to provide a reasonable number of relevant results. All of the available resulting articles were downloaded from Google Scholar and screened through several "filters." The first filter, Filter 1, isolated only journal articles. Filter 2 isolated articles published no earlier than 1996. Next through Filter 3, only those remaining article proposing a unique taxonomy were isolated.

The selected articles were then reviewed further in more detail to determine the relevance of the taxonomy. Those focused on robots in a more general sense, their physical components, and/or the users were considered to be relevant. Additionally, any taxonomy referenced in these articles was added to the review. The motivation, objective, focus, categorization criteria, limitations/exceptions, and any definitions from each of the selected taxonomies were noted. Taxonomies with similar motivation, objective, and/or focus to those of the project were noted. The categorization criteria chosen in these taxonomies may be drawn on to build a unique prescriptive taxonomy.

3.2 RoboBusiness Study

The following sections outline the processes used during the interviews with various robotics professionals conducted at the RoboBusiness Leadership Summit.

3.2.1 Motivation

During the background research and literature review, our IQP group encountered news that there would be an industrial conference, RoboBusiness Leadership Summit taking place on November 2nd and 3rd, 2011, in Boston, Massachusetts sponsored by Robotics Trends and iRobot. All team members agreed that we needed to gain a better understanding of the direction in which health care robotics is headed, and that interviewing a few industry professionals currently working in the field of robotics would help us do that. More specifically, we decided to interview people representing robotics companies that specialize in health care (both clinical and non-clinical). We are confident that these individuals will provide valuable insight into the current state of the robotics industry in regard to health care and will allow us to successfully accomplish our project goal of proposing a health care robot that will help optimize the effectiveness of a specific focus area in health care.

3.2.2 Data Collection

Team members attended the conference representing WPI Robotics. To collect the desired data, we intended to interview professionals in the robotics industry, working from the WPI Robotics booth. We conducted a total of seven 10- to 15-minute long interviews at the conference and reception periods in person, recording the interviews with an audio recorder. Interviewees were chosen by the list of featured presenters and by personal contact during the exhibition period. The conference was being held for two days. The team was required to be separated into groups of no more than two team members because the conference pass was for a limited number of students. For the first day of conference, Kevin Malehorn and Hosung Im attended and interviewed Colin Angle, Dan Kara, and Thomas Ryden. Kevin was conducting the interviews and Hosung was taking notes and supporting Kevin's moderation. For the second day of conference, Wan Liu attended and interviewed Corey Clothier, Ted Larson, Paul McGrath and Erin Rapacki (see Table 3.2.1).

Table 3.2.1 – Basic Information of Industry Experts

Basic Info / Subjects	Position	Years have been in the industry
Colin Angle	CEO, Co-founder and Chairman of the Board of iRobot Corp.	21
Corey Clothier	Business strategist of the US Army	3
Dan Kara	President of Electra Studios, past-President & founder of Robotics Trends, founder & chairman of RoboBusiness	21
Ted Larson	CEO and Co-founder of OLogic	8
Paul McGrath	Regional sales manager for Maxon Motors	18
Erin Rapacki	Product marketing manager of Adept Technology	10
Thomas Ryden	COO & co-founder of VGo Communications	11

The interviews were relatively concise and completely verbal (recorded). The following are the interview questions used at the RoboBusiness conference:

1. What is your current professional position? How long have you been involved in the field of robotics?
   (Follow-up question) How familiar are you with the application of robotics in health care? How about specific applications for home care for elderly?
2. There are numerous applications for robotics in health care. Which current applications do you see as being the most effective (in terms of cost, functionality, and profit/value)?
3. Specifically which area of health care robotics do you feel is developing most rapidly (telepresence surgery, prosthetics, patient monitoring, rehabilitation, elder care)?

4. The average person is nearly constantly exposed to technology. What is holding robotics back from becoming part of our daily lives as, for example, smart phones have become? Cost? Scarcity of materials? Lack of demand?
5. Is there anything else you would like to add about the application of robotics in health care?

The information gathered, including any identifying information, remained confidential unless incorporated into the report (identifying information was ONLY disclosed with the consent of the interviewee).

3.3 WPI & Summit ElderCare Focus Groups

The process of designing, structuring, modifying, and carrying out all three focus groups was not only beneficial to the progress of the project, but to the experience of the team members as well. Throughout this multi-week process, the team gained an understanding of how to design a focus group, both through literature review and iterative experience gained while running the focus groups, and even between focus groups. The initial background information allowed the group to design an acceptable focus group that also served as a kind of "test run" for the following focus group. Not only did the first focus group, performed at WPI, give the team some interesting results, it also highlighted the areas that needed (or did not need) improvement. This allowed the team to design a more focused, objective-driven second and third focus groups. Needless to say, the results from the later focus groups were much closer to what the team was looking for, thanks to the redesign of the objectives and protocol.

Motivation

Our IQP team held two focus groups on campus during B term, and one off campus at Summit ElderCare. From these in-depth, qualitative studies, the team hoped to gain an initial knowledge of the public's opinion of our project topic. The team wanted to conduct focus groups with WPI students and employees, as well as the elderly and their caregivers in order to help gauge the appeal of various eldercare robotics products in addition to robotics in general, as well as compile any additional concerns or opinions regarding robots. The gathered information would be analyzed and applied to our taxonomy to gain a better understanding of the relationship between each specific robot and its appeal to potential consumers. Ultimately, the data from these focus groups should help the team determine the requirements for the implementation of an eldercare robot.

IRB Approval

For all the focus groups conducted that involve human subjects, the team obtained WPI Institutional Review Board (IRB) approval before collecting data. The team submitted documentation describing the motivation, objectives, procedure, and data collection methods (discussed later), and the WPI IRB determined that these no-risk studies were acceptable to perform. For further information or concerns regarding the IRB, please contact Kent Rissmiller, the director of WPI's IRB.

Data Collection

The team conducted the same processes to collect data for all focus groups. The study was recorded using an audio recorder. The data was transcribed from the audio recorder to a text document. The audio recording was subsequently destroyed and the text document was be stored securely on the team's SharePoint site. No personal or identifying information was requested of the subjects participating in the study, and any such information collected unintentionally would be destroyed immediately. The subjects were not in any sort of risk by participating in the study.

3.3.1 WPI Focus Groups

Objectives

As mentioned previously, the original objectives for the first focus group, while thought out and based on past experience and research, were somewhat vague. Generally, the IQP team was looking to gather opinions of the participants concerning acceptance, some desired functionalities, and insights into feasibility of home health care robotics.

This led to a loosely-defined protocol, with questions and discussion topics that weren't always relevant or necessary. Over the course of the first focus group, the team realized this was the case, and made some changes for the second focus group. In general, the objectives were too vague for the first focus group. For the second, the group wanted to figure out what kind of health care robot the participants may want most for themselves (in the future) or their family members (either now or in the future).

This approach led to a much-improved focus group the second time around, giving the team data that was more relevant to the subject at hand, and was more evenly split between desired functionality and acceptance. In general, the team tried to get answers to the following questions, in terms of functionality and other requirements: "What kind of robot would you want when you're older?" and "What kind of robot may your grandparent want?" This gave the second focus group more of a focus on functionality, in order to match the popularity of the acceptance discussion.

Sample Recruitment and Characteristics

Originally, the team had well-defined but overly strict guidelines for recruitment of the desired demographic. Instead of splitting the interested students and employees into Robotics Engineering-based (RBE) and non-RBE groups, as well as requiring certain survey responses as originally planned, the team used a more open recruitment method. Broad recruitment strategies were used (campus-wide emails and flyers), looking for any students with interest in assistance or health care robotics. Those interested were instructed to send an email to the IQP team, indicating their major and class year.

This recruitment method worked well enough to fill two focus groups of five people each, with both WPI students (ages 18-25) and employees. More specific information regarding the participants is shown in the Results section 4.1. Both focus groups met for approximately one hour each; the first took place in a small classroom on campus in the evening, while the second was located in a conference room on campus around lunch time. Food was provided for the second focus group.

For consistency, Kevin Malehorn moderated both WPI focus groups. The three other team members observed, took notes, and contributed with occasional questions that seemed topical or that the moderator may have missed. This strategy not only allowed the moderator to focus solely on the discussion at hand, it also gave the moderator an opportunity to accumulate experience in conducting focus groups.

Protocol

The protocol for each focus group was based heavily on the objectives created for each. The first looked more for the participants' opinions concerning acceptance of personal health care robots. A summation of the protocol for the first focus group can be seen below.

Before the focus group began, the subjects were informed of the general content that the study covered. They were also reminded that no personal information will be disclosed in any way, and that they have the right to leave the study at any point if they so wish. The two focus groups were conducted using the same two-phase structure.

PHASE I: *Introduction*

Essentially an “ice breaker,” basic information about the project and the team’s motivation and objective for the study were introduced to the focus group. Next, the group was directed towards general discussion, eventually focusing more on the team’s goals for the study. This portion of the study sets up the next discussion and presentation focused on robotics in health care. This phase should last 15-20 minutes.

PHASE II: *In-Depth Discussion*

In this phase, the moderator introduced robotics as a means of better meeting the health care needs of the elderly to the focus group. The group was asked to discuss the following two points:

- Do robots have the potential to practically and cost-effectively improve the average standard of health care that the typical individual is entitled to?
- Why have personal health care robots not caught on in the US?

Following the discussion, the group was shown a PowerPoint presentation containing information regarding several eldercare robots, introduced below. After each product was presented, the subjects were asked for their opinions about the products (see questions in Table 3.3.1). The subjects were encouraged to discuss these opinions in order to bring up any concerns and/or ideas for improvement they may have had.

Table 3.3.1 – Introductory discussion questions used in Phase I of the first WPI focus group.

What do you think are the basic needs of the elderly?
Does health care in its current state adequately meet these needs? How so?
What is the role of health care in the lives of the elderly? What do you think it should be?
Would the implementation of additional technology aid or hinder health care?

Roomba

Roomba, as seen in Figure 3.3.1, is the star product from iRobot, the famous robotics company. Roomba is an automatic robotic vacuum cleaner that uses sensors to avoid walls or stairs and automatically recharge itself when it ran out of power.

Figure 3.3.1 – iRobot's Roomba, an example of a household assistance robot.

Paro

Paro is an advanced interactive therapeutic robot designed to stimulate patients with Dementia, Alzheimer's, and other cognition disorders [66], [67] (see Fig. 3.3.2).

Figure 3.3.2 – Paro, a form of companion and mental therapy robot.

eNeighbor

The eNeighbor remote monitoring system (Fig. 3.3.3) allows residents to retain their independence and improve safety and security, health and wellness at the same level of independence as residents who wish to live at home.

Figure 3.3.3 – eNeighbor was used as an example of a robotic system designed for monitoring.

Toyota Healthcare

Toyota healthcare robots (Fig. 3.3.4) can lift disabled patients from their hospital beds or help them walk which provide assistance to residence with disability and care givers.

Figure 3.3.4 – A couple of examples of Toyota Healthcare's rehabilitation and physical assistance devices.

Table 3.3.2 – Questions for discussion surrounding the robots presented in the first WPI focus group.

What is your first impression of the product?	Do you believe the product's service is valuable?
	Is this product worth the cost?
	Is this product likely to catch on in the future?
	Could you see yourself using this product?
What may be some unintentional or secondary effects of the product?	May this product potentially be abused by its users?
	May the product displace health care working, thus damaging the job market?
Is the product user friendly?	What changes might make the product more user friendly?

The first focus group gave the team a better perspective of what was important to remove or include for the second focus group. Therefore, the second focus group, with newly redesigned objectives, was aimed more at discussing functionalities of health care robots, and the usefulness and feasibility of those functionalities. The changes made to the protocol between focus groups can be seen in Table 3.3.3.

Table 3.3.3 – Changes made between WPI focus groups.

Icebreaker refined	Gauge personalities of subjects
	Start casual discussion/conversation
	Relatable topics: Moobella machine, Yaskawa-kun robot
Present IQP more concretely to give subjects a better idea of the purpose of the focus group	Purpose: requirements for healthcare robot
	Motivation: worker shortage, growing elderly population, rising healthcare expenses
	Definition of robot: sense, think, act; autonomous
Rethought objective to focus discussion & outcomes of study	Functionality
	Acceptance (including ethical issues)
Added scenario to give context to discussion	Grandmother that needs help in many areas
	"In what way could robots help her?"
Replaced some example robots to give better idea of function categories & allow for more relevant questions	Roomba - household assistant
	PARO - therapy/companion
	eNeighbor - monitoring (decentralized system)
	Toyota Healthcare - physical assistance/rehabilitation
Eliminated unnecessary questions	General questions, too broad to give good results
	Their idea of what a robot is (this could arise during discussion regardless)
	How often they interact with/care for elderly (will also arise in discussion)

This change to the protocol provided results that would prove to be more useful later on, when the team was analyzing the functionality with the most potential of acceptance and usefulness. By focusing on specific applications, and the participant's discussion-guided opinions, the second focus group yielded better and more results than the first. The second focus group's protocol can be seen below.

PHASE I: ***Introduction***

Phase I began with a brief description of our IQP, to give participants a better idea of what the team is studying, and what kind of topics would be covered over the course of the focus group. The introduction covered these points, as well as a few initial, general questions, which can be seen in Table 3.3.4.

Table 3.3.4 – Short topics covered during the introduction of the second WPI focus group.

Brief description of our IQP	Robotics in smart health care, focused on elder care specifically
	Statistics (simplified) demonstrating why the elderly population is our demographic of choice
	General information about how much assistance elderly need, which tasks, etc.
General introductory questions	What impact do you think robots could make?
	What role could robots play in the lives of the elderly? Companion? Assistant? Monitoring?

PHASE 2: ***Realistic Connection, Examples***

The second phase introduced a scenario, as shown in Table 3.3.5. This scenario served to ground the discussion in order to pull realistic suggestions from the participants. The scenario and follow-up questions can be seen below.

Your grandmother is lonely. She lives alone and is retired and rarely goes out, aside from doctor visits due to a medical condition. She cannot drive, despite having to make frequent trips to see her doctor. Her condition also often has her bed ridden, so she has trouble keeping up *with housekeeping. When she is not in bed, her bad knee requires her to use a cane to get around her home.*

Table 3.3.5 – Follow-up questions to the presented scenario. Aimed to further explore participants' opinions of functionality and acceptance in robots for the elderly.

Functions: **How do you think a robot could improve her situation? What would it have to do, realistically?**	Companionship
	Monitoring
	Physical Assistance (rehabilitation, wheelchairs)
	Housekeeping
Acceptance: **What influences the acceptance of robots among the elderly?**	Comfort (privacy, responsibility)
	Cost
	Functionality provided

Part of Phase II involved the reintroduction of several robots, as shown earlier. These four examples were specifically chosen because they each fit into a distinct role a robot could fulfill. By presenting and discussing these robots, the team was able to get feedback on real applications of robotics.

At the end of the focus group, the IQP team revisited the scenario, inviting participants to voice any final thoughts and opinions surrounding the various robotic solutions discussed over the course of the study. After final comments were addressed, the focus group was adjourned, and participants were thanked for their participation. A follow-up email was sent, thanking them again, and providing them with the focus group materials and the opportunity to find more information about health care robotics on their own.

3.3.2 Summit ElderCare

The Interactive Qualifying Project (IQP) team held one focus group at Summit ElderCare (277 East Mountain Street, Worcester, MA) promptly following Thanksgiving break. The in-depth, qualitative nature of the study would serve as an initial exploration of our topic.

Objectives

The Summit ElderCare focus group was conducted after the two WPI focus groups. The team selected questions that received good feedback in the first two focus groups and developed new questions based on the previous protocols. The questions were refined according to the two distinctly different demographics: the care givers and the elderly. The protocol was developed to gain insight into the users' opinions and needs.

The objectives for caregivers and the elderly were a little different based on their roles. Because caregivers could be the potential users working with the health care robots, the team was looking for their opinions as secondary users. The team hoped they could provide opinions on their preferences of robots that they would likely to work with. Moreover, caregivers would also provide valuable feedback concerning the functionality of robots as they have had first-hand experience taking care of the elderly. The team gathered the opinions of the elderly regarding the functionalities and constraints of a health care robot that would cater to their needs. Considering the needs of this demographic is imperative, as they will be the primary users of our device.

Demographic and Recruitment

Professor Padir, as one of the advisors for the team project, contacted Dr. David Wilner and Richard Burke of the Fallon Community Health Plan (FCHP) about the possibility of conducting focus groups at the FCHP-founded Summit ElderCare. Mr. Wilner put the team in contact with Annamaria Salisbury, the site director of Summit ElderCare. Based on the tight schedule of the caregivers and patients, the team finally chose noon as the time to visit Summit ElderCare, as this was when most participants would be available.

The subjects were recruited on-site by Ms. Salisbury. Originally the team planned to conduct two focus groups, separating the elderly and caregivers, but ended up combining the two groups due to limited space at Summit ElderCare and a limited number of elderly participants. This required no major changes to the protocol; any questions meant specifically for either the elderly or the caregivers could simply be directed towards that group.

The focus group was comprised of 4 elderly (ages 65-80) and 3 caregivers (ages 40-65). More specific information regarding the participants is shown in the Results section 4.3.3. The focus group took approximately one hour and 15 minutes due to some waiting and set-up time in the beginning. The focus group took place in a small conference room in the Summit

ElderCare facility.

For consistency, Kevin Malehorn continued as the moderator for Summit ElderCare as he did for the two WPI focus groups. The three other team members observed, took notes, operated the PowerPoint, and contributed with questions and comments that seemed critical or that the moderator may have missed. This strategy had been practiced and worked well during WPI focus groups so the team continued using it.

Protocol

Two protocols were originally prepared for the elderly and the caregivers, but the team combined the protocols at the focus group because there weren't enough participants for two separate focus groups. The protocols were directly based on objectives created for each targeted group. A summary of these protocols can be seen below.

Before the focus group commenced, the subjects were informed of the general content that would be covered by the study. They were also reminded that no personal information would be disclosed in any way, and that they had the right to leave the study at any point if they so wished. The focus group was conducted using the same two-phase structure as the WPI focus groups. Each phase is described below:

PHASE I: *Introduction*

Essentially an “ice breaker”, the team introduced each team member, Worcester Polytechnic Institute, and the team's Interactive Qualifying Project. In the introduction, we introduced the current background of robotics in smart health care, explained our purpose, and showed some facts and figures which best explained our motivation. The team then asked each participant about their current situation, as well as some information about Summit ElderCare. The background questions covered the areas indicated in Figure 3.3.5.

Figure 3.3.5 – *Background questions for the elderly*

Besides those questions, the team also inquired about information of life at Summit ElderCare from the three categories seen in Table 3.3.6:

Table 3.3.6 – Questions for the elderly about life at Summit ElderCare

What are the daily procedures and activities at Summit ElderCare?
What are your [participants'] opinions about attending Summit ElderCare?
Why did you [the subjects] choose Summit ElderCare?

Those questions helped the team to gain a better idea of the way the elderly live, and also provided basic information about what the subjects thought of Summit ElderCare. At the end of the introduction session, we had learned that all subjects preferred to live at home as long as they can, that's why they chose Summit ElderCare.

This portion of the study sets up the next discussion and presentation, focused on robotics in health care. The next phase lasted about 25 minutes. The questions asked in this section are shown in Table 3.3.7.

Table 3.3.7 – Interview questions for the elderly and caregivers at Summit ElderCare

Elderly	What could a robot do for you?
	What do you need assistance with most often?
	What is something you have trouble with?
	If you could have a robot at home to help you with anything, what would that be? What would it do for you?
	What would make you more comfortable around robots?
Caregivers	For you as a caregiver, what is the biggest issue?
	What could a robot do to help you with your job?
	What is the most important thing you provide for participants? (What kind of robot might a participant need?)

There were also some follow-up questions which were used to clarify or stress some topics that the team had interest in. Please refer to the data analysis chapter for more information.

<u>PHASE II:</u> In-Depth Discussion

Following the discussion, the group was shown a PowerPoint presentation containing information regarding several eldercare robots. After each product was presented, the subjects were asked to evaluate the products (with the questions seen in Table 3.3.2). The subjects were encouraged to discuss their opinions in order to bring up any concerns and/or ideas for improvements to these robotic products.

Presentation of Robots

In the Summit ElderCare presentation, the team showed the same robots used in the WPI focus groups. Each robot was an example of one of four functionalities: assistance, companionship, monitoring, and rehabilitation. Please refer to the WPI focus group methodology (section 3.3.1) for more information about these robots. After the presentation of the products, the subjects were given the opportunity to bring up any last thoughts regarding the discussion topic.

At the end of the focus group, the IQP team invited participants to voice any final thoughts and opinions they may have had concerning the various robotic solutions discussed over the course of the study. After final comments were addressed, the focus group was adjourned, and participants were thanked for their participation. A caregiver and her father invited the team to pay a visit to their home to observe their lifestyle and daily difficulties. We thanked them for their offer, but had to refuse due to the project's tight schedule.

3.4 Data Analysis (Coding Methodology)

Background

In order to analyze the data collected from the studies described in sections 3.2 and 3.3, the IQP team investigated qualitative data analysis strategies. In general, most qualitative data analysis strategies (such as Grounded Theory) focus on summarizing, categorizing, and organizing ideas into common themes. From these themes, theories and end results of the study can be hypothesized.

There are many ways to approach the Grounded Theory of data analysis; our group's method was based loosely on the ideas presented by David Gray in *Doing Research in the Real World* [73]. This text highlighted the importance of coding one's data by identifying and organizing recurring ideas and themes. As the first step in the Grounded Theory approach, open coding consists of identifying which kind of themes (or “codes”) each specific point of data has. Axial coding is the next step, in which relationships between categories were recognized. Finally, selective coding is meant to provide a look at the specific ideas and common themes in order to draw overarching conclusions and theories from the data.

The Team's Approach

The team first went through all of the recorded audio files obtained from the various focus groups and interviews. The audio files were transcribed directly into an open coding format (bullet-points of raw data) with only meaningful direct quotations recorded. Following axial coding procedures, categories were generated and correlated to each other. Based on the axial coding, we used Microsoft Visio to visualize the variety of opinions, codes, and themes from the focus groups. After the codes of each focus group were visualized, we were able to clarify the key themes and points revealed by each focus group. This strategy of coding and theme formation it helped the team to develop thoughtful Results and Discussion chapters. Chapter 4 (Results) will contain data organized by themes from the coding process, and include our interpretations of the data obtained from the focus groups and interviews with industry professionals. These interpretations will be briefly included throughout Chapter 5 (Discussion). We will integrate our interpretations of the data with the taxonomy in order to specify and discuss requirements for a home health care robot, provide potential designs for such a robot, and investigate future trends of robotics in smart health care.

4 Results

This section summarizes the results of the various studies we conducted, namely focus groups at WPI and Summit Eldercare, interviews at the RoboBusiness Leadership Summit, and the taxonomy literature review. We conducted a total of three focus groups, held seven individual interviews with professionals involved in the robotics industry, and developed taxonomy of robots.

4.1 Taxonomy

In order to identify an appropriate application for robotics within health care, several factors need to be considered carefully. Naturally, the main considerations are the robot and the value of its functionality as well as the needs, intentions, and expectations of the people that are going to interact with it. Thus, in order to relate the user's needs and preferences to an appropriate robot functionality and develop a set of user requirements (the main objective of the project), we have endeavored to characterize the different dimensions of the user, robot, and their interactions in the form of a taxonomy. The dimensions to be discussed in the following sections are the roles, freedom of interaction, and expectations of the user in addition to the various components, morphologies, architectures, and degrees of autonomy of the robot.

4.1.1 User

The user, which we define as any person who will interact with a functioning robot at some level, has specific needs and expectations that must be fulfilled, and thus is the first factor to be discussed. We break users down into either primary and secondary users. We have defined primary users to be those affected directly by the robot with which they interact, generally in a beneficial manner. In other words, a robot's functionality should be tailored to the needs and expectations of its primary user, as this is the user the robot is intended to serve. Secondary users interact with the robot to control, maintain, and supervise it. These users do not necessarily benefit from the robot's functionality, but are vital to its operation, granted the primary user is unable to carry out these additional responsibilities. Primary and secondary users may be divided further based on the role they assume upon interaction with a robot. The various roles a user can assume, namely peer, commander, operator, and supervisor are described in the following subsection.

User's Role

Different users can interact with a robot in different ways, thus inherently assuming a specific role. Additionally, one user can assume a multitude of roles, depending on the robot in question. Drawing from possible roles proposed by Grabowski et al. [74], these various roles can be categorized as a peer, supervisor, commander, or operator. In Grabowski's taxonomy of command and control structures, however, there is one additional category labeled "observer." We exclude the observer because, by their definition, an observer does not interact with a robot and therefore should not be considered a user by our definition. The possible user roles are defined in detail in the following paragraphs.

Peer

A user assuming the role of a peer interacts with robot, either actively or passively, but does not control the robot [74]. Active interaction implies that the user is aware of the robot and willingly decides to interact with it. Passive interaction implies that the robot collects data from the user without the user's conscious input. This role is often associated with a primary user because a peer interacts with a robot in order to receive information, assistance, or entertainment. Thus, a peer is generally, but not necessarily, a beneficiary of the service the robot provides. As demonstrated in Figure 4.1.1, the robot senses the user and then acts in such a way as to impact him/her. This is the most limited role a user can assume as far as controlling the robot is concerned. For

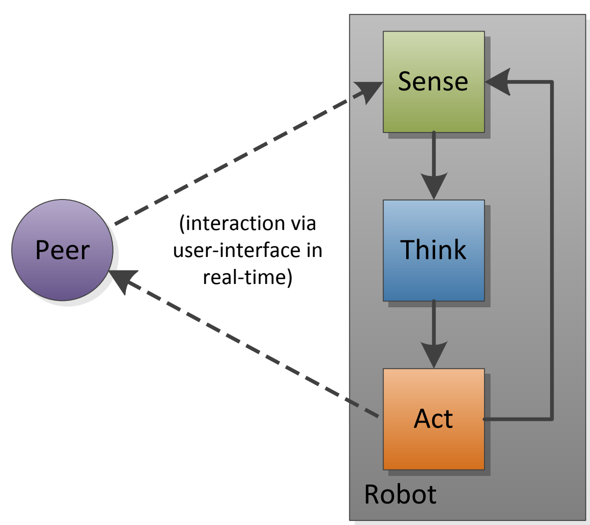


Figure 4.1.1 – Role of User – Peer

example, any commands posed by a peer are executed by the robot in a manner the robot finds to be most appropriate based on its programming or the input of a secondary user assuming the role of commander or operator – the peer does not take part in task execution. The diagram above demonstrates the simple interaction.

EXAMPLE: An example of a peer would be the primary user of HealthSense's eNeighbor monitoring system. In this simple robotic system, the user is monitored by means of several sensors collecting information, namely the user's eating, sleeping, and bathroom habits. The only way the user can *actively* interact with the robot is by means of a button intended to be used in case of emergency. In the event that the button is engaged, the system alerts a nurse on staff (secondary user), who at that point assumes the role of operator and decides what to do next.

Commander

Many robots do not require direct control from a user, but rather need to be programmed with specific tasks, functions, and/or objectives. A user that selects these tasks and objectives assumes the role of a commander. Their main responsibility is to provide the robot with the information it will need to carry out a specific task before actual task execution. This type of user essentially programs the robot in question to perform a task when it is requested by a peer.

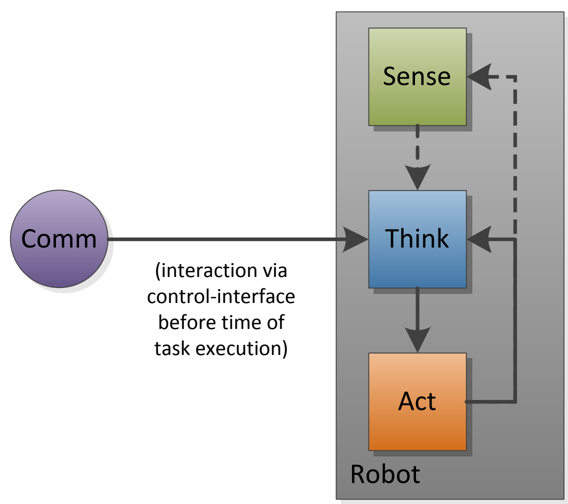


Figure 4.1.2 – Role of User – Commander

The instructions given to the robot can be very simple, allowing the robot to achieve the objective by its own means (i.e. make decisions based on environmental stimuli), or a highly detailed sequence of actions the robot will perform, sometimes in repetition (Figure 4.1.2). This type of role is common in manufacturing, for example, where robots are programmed to perform repetitive tasks without any additional human intervention (apart from supervisory control). Robots associated with this type of user are similar to those requiring only supervisory control and exhibit anywhere from limited to high levels of autonomy as well.

EXAMPLE: An example of a commander would be the secondary user of the iRobot's Roomba, namely the person who programs the robot's vacuum sequence. The commander in this case inputs a series of code on which the Roomba will base its decisions during the vacuuming process. The Roomba identifies dirty areas and cleans them more thoroughly and avoids obstacles. It carries out these tasks based on a combination of environmental stimuli and its initial programming. The primary user, or peer, does not influence task execution.

Operator

Robots often require humans to assume the decision making process and act as the surrogate intelligence [74]. A user that assumes the responsibility of directly controlling a robot is called an operator. The operator decides what actions the robot performs and instructs it to do so in real-time. The operator subsumes the responsibility of thinking for the robot, as seen in Figure 4.1.3. Grabowski et al. state that this process is most often performed remotely, and is hence called tele-operation. A tele-operated robot requires much attention and a user-interface that provides sufficient sensory information and control to the user. This role is associated with robots that possess limited autonomy (robot autonomy is discussed in more detail in Section 4.1.2).

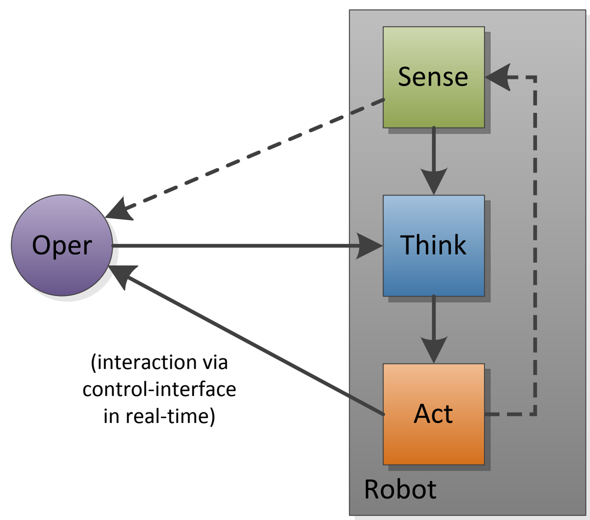


Figure 4.1.3 – Role of User – Operator

EXAMPLE: The primary user of the VGo Communication's mobile tele-present communication robot can be considered an operator. The user directly controls the robot's movement in real time. The robot can relay video and audio from its local environment to the user so as to allow him/her to direct the robot successfully.

Supervisor

Robots that are capable of functioning on their own (capable of making decisions to some extent) require only supervisory control. A supervisor's responsibility is to monitor the robot's performance and provide direction only when necessary, i.e. in the event of malfunction, emergency, etc. Thus, a supervisor can be said to assume the role of operator only when intervention is required, as is demonstrated in Figure 4.1.4. Robots that require supervisory control tend to exhibit high levels of autonomy.

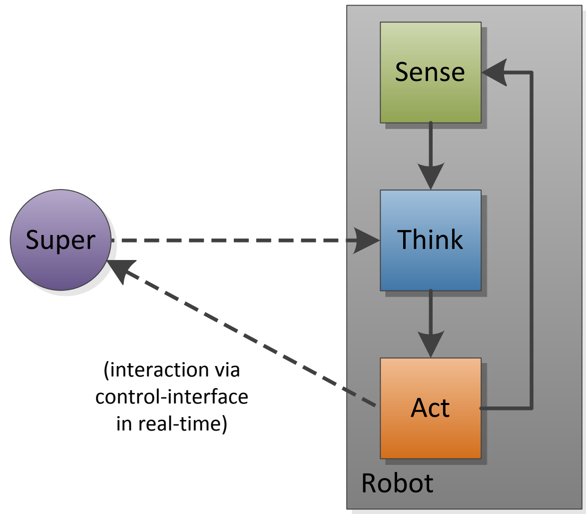


Figure 4.1.4 – Role of User – Supervisor

EXAMPLE: An example of a supervisor is the secondary user of HealthSense's eNeighbor robotic monitoring system, namely the personnel on staff ready to react to emergencies. The medical personnel do not interfere in the operation of the monitoring system until the primary user engages the emergency button for help. At this point the supervisor acts as a surrogate intelligence for the robot and decides what to do next (i.e. notify paramedics, family members, doctor, etc.). In this particular case, each supervisor is responsible for several eNeighbor systems.

With these roles defined, it is possible to begin to identify certain user requirements for a particular robot, namely the user interface, depending on its intended functionality, its level of autonomy, and the roles of the users that will be interacting with it. However, to better understand which type of user interface is appropriate for a particular application, the user has to be defined in more detail still. The freedom of interaction, needs, and expectations of the user are discussed in the following two subsections.

User's Freedom of Interaction

This section helps define the different levels of freedom of human-robot interaction for different users. Salter et al. [75] state that in order to interact with a robot and benefit from its functionality, some freedom of interaction is inherently compromised. Additionally, operating instructions, particularly when there is a specific objective to be achieved, compromise this freedom further because in this case the user is limited to interacting with the robot in such a way as to achieve the objective. As mentioned previously, this limited freedom is inherent and would not greatly hinder the acceptance of the robot. There is another factor that may limit the autonomy of the user, namely a handicap. A user that is deaf, blind, mute, or physically/mentally handicapped in any other way will experience a limited freedom of interaction with a robot that is not designed to meet their special needs. Therefore, it is important to understand and consider the special needs of intended users when designing a user interface, whichever role the user may assume. Essentially, the designer must decide where the user fits in Figure 4.1.5.

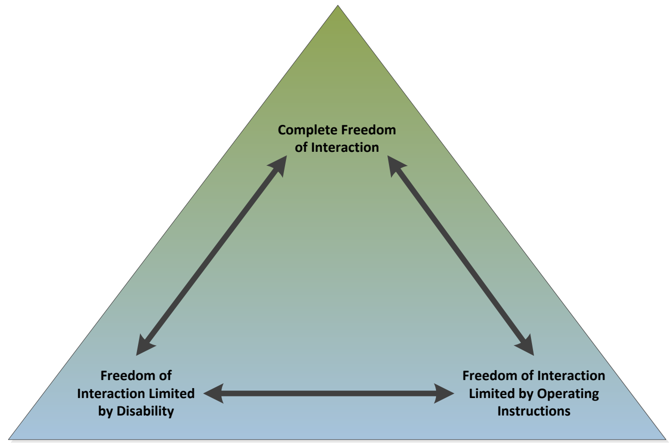


Figure 4.1.5 – Degrees of Freedom of Interaction

User's Expectations

In order to be a marketable product, a robot must meet the expectations of the consumer, or in this case the potential primary user. The robot must fall within an acceptable price range, have a desired functionality, and be easy enough to use and maintain (depends upon user preference). Additionally, the amount of privacy a user is willing to compromise should be considered as well. It must maintain a non-overwhelming presence, i.e. stay out of the user's way. These metrics can be determined by studying the intended consumer demographic by means of interviews, surveys, and focus groups as well as studying consumer trends. It is important that the expectations of potential users are well understood by a robot designer because without interested consumers, a robot is useless regardless of its functionality and the service it may provide society.

4.1.2 Robot

With the dimensions of the user characterized, we can now turn our focus to the different types of robots. First, however, the main underlying constraint must be defined. Because we are attempting to characterize robots, we must define the term “robot” itself. Figure 4.1.6 visualizes our definition of a robot. We drew on a definition proposed by Boni and colleagues [76] and developed the following definition:

A robot is a machine that is capable of obtaining information from its environment by means of sensors and manipulating that information into a form that can be utilized by an actuator – locally or remote. Using this definition, we can begin the characterization process.

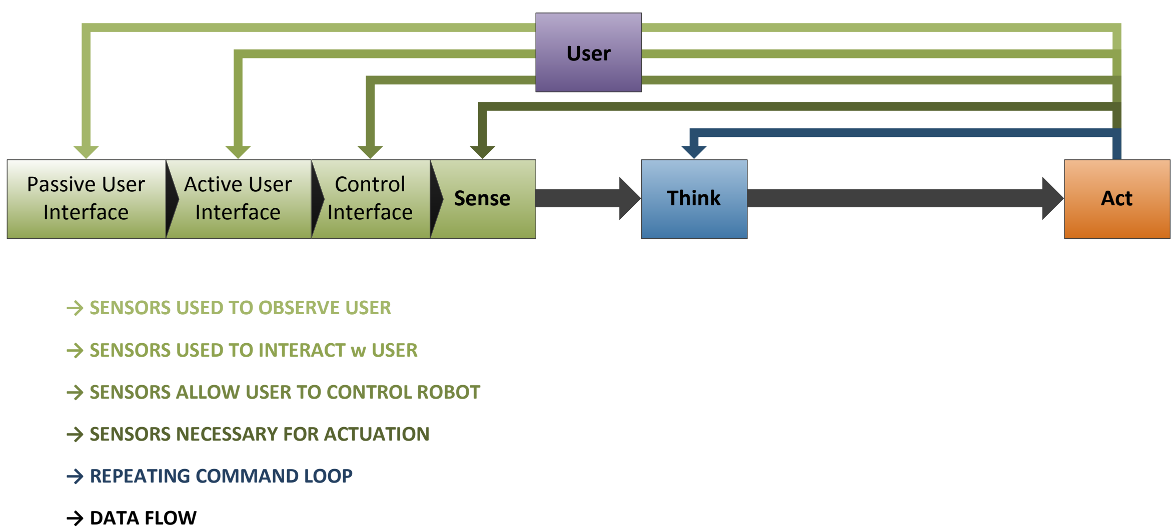


Figure 4.1.6 – Data Flow in Robot

The first classification criterion to be discussed is the robot’s physical components – its sensor(s), processor(s), and actuator(s). Additional dimensions to be discussed include morphology, architecture, and autonomy.

Unlike Yanco and Drury [77], who claim that “it is much more important to consider how the [robotic] system provides decision support in the interface […]” than to consider the input/output devices of a robot as suggested by Agah [78], we believe that is necessary to consider both of these aspects in our categorization of robotics: The input/output devices (sensors/actuators by our definition) have a direct correlation with the cost of the robot, and therefore its marketability, and its interface has a direct correlation with user-acceptance, therefore also having an effect on its marketability as well. Because certain input/output devices essentially compose the user-interface, we intend to characterize the components individually.

Sensors

By our definition, a robot must be able to collect information from its environment using its sensors. A robot can collect visual, auditory, physical, and chemical data with a variety of different sensors that react to different stimuli. The various types of sensors are broken up according to the type of information they collect below:

Visual: Sensors that are capable of "seeing" their environment and producing data that can be processed (constituted primarily by cameras - 3D, thermal, infrared, etc.).

Physical: Sensors that are capable of "feeling" their environment, whether directly or indirectly, and producing data that can be processed. Physical stimuli that physical sensors are reactive towards are pressure, motion (acceleration, deceleration, relative direction, relative speed, etc.), position, and temperature.

Auditory: Sensors that are capable of "hearing" their environment and producing data that can be processed (constituted primarily by microphones - audible frequencies, inaudible frequencies, etc.).

Chemical: Sensors that are capable of "tasting" their environment - sampling their environment and detecting the chemical composition of the sample (constituted by biosensors, air samplers, liquid samplers, etc.).

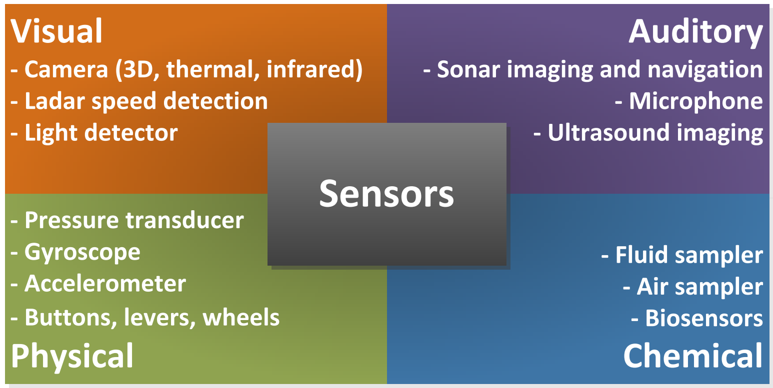


Figure 4.1.7 – Various Types of Sensors with Examples

Actuators

Additionally, a robot must be able to actuate based on the information it collects and manipulates. This is obviously taken care of by actuators. Like sensors, actuators can perform several different kinds of functions. A robot can produce light and image based visual responses, physical mechatronic responses, sound based auditory responses, and/or chemical responses with the appropriate actuators. The various types of actuators are discussed in more detail below:

Visual: Capable of displaying images or videos, producing light, etc. by means of screens, projectors, lamps, etc. Visual actuators are often vital parts of a machine's user interface.

Physical: Capable of creating motion or giving tactile or haptic feedback, etc. Motion can be used for transport, as part of the user interface, manipulating the environment, etc.

Auditory: Capable of conveying data to the user using sound, mainly by means of speakers. Auditory actuation can range from single tones to synthesized voices.

Chemical: Release chemicals in order to maintain a certain balance, treat a disease in a human or animal, etc.

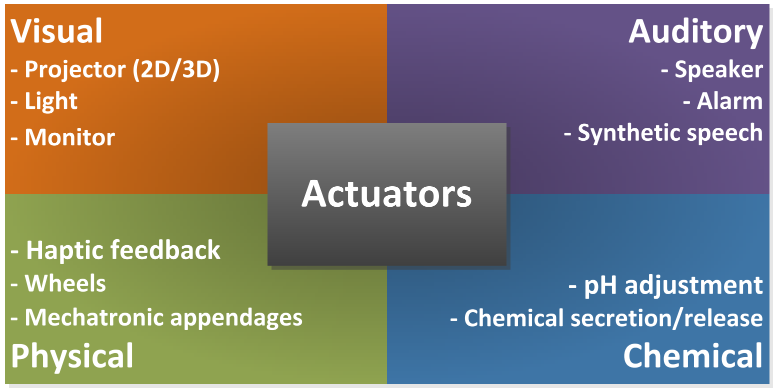


Figure 4.1.8 – Various Types of Actuators with Examples

Processing Hardware & Software

The third component, the *processing capability* of the robot, can be divided into three sub-categories: the robots processing hardware, its software, and its means of internal data communication – essentially the central nervous system of a robot. The robot's hardware consists of the CPU, memory storage, and routers/satellites/antennas, all of which can be measured quantitatively. The computing hardware is what determines any limitations of the software (data manipulation/interpretation): Stronger processing capability allows more sophisticated software to be operated by the robot. A robot's software can be measured relative to the software currently available. Generally, better software implies a more "intuitive" thought process. The more data manipulation that occurs, the more sophisticated the software. In other words, a robot's processor that is able to manipulate and interpret data in higher quantity, complexity, or in less time would be considered as "highly-capable."

We call the metric used to determine the overall complexity of a robot "relative capability," which is in turn defined by the quality (precision, strength, specialization, etc.) of a sensor, processor, or actuator relative to existing technology. By our definition, a high quality, "highly-capable" component would be the most sophisticated technology currently available, such as an ultra-precise gyroscope or high-definition 3D camera. While a highly-capable component can provide greater functionality, it can also be far more expensive than a less-capable component. A highly-capable component may also be more prone to failure, thus raising the cost of the robot even more in terms of maintenance. A low quality or "inferiorly-capable" component would be a run-of-the-mill device that is simple and cheap to produce, such as a simple motion detector or pressure transducer. An inferiorly-capable component can be used to build a more economical robot, but may lack functionality.

Morphology

In their updated taxonomy of human-robot interaction, Yanco and Drury [79] state that robot morphology is an important consideration because people react differently to different kinds of robots. They decided that three categories, *anthropomorphic* (human-like appearance, such as ASIMO in Figure 4.1.9), *zoomorphic* (animal-like appearance, such as Paro in Figure 4.1.10), and *functional* (appearance related to function), are sufficient to characterize robot morphology. Robot morphology plays a significant role in user acceptance: In Japan, anthropomorphic robots are very popular, whereas in the United States, robots generally assume a functional appearance. Morphological preference is heavily influenced by societal perceptions of robots and the roles they play in our lives.

Figure 4.1.9 – ASIMO

Figure 4.1.10 – Paro

Architecture

The architecture of a robot characterizes the manner in which its physical components are organized in space, as well as how a robot interacts with other machines in its environment. Robots may be comprised of localized (components contained within the “body” of robot) or delocalized (one or more components dispersed throughout environement) components and may function individually, as part of a system (where it is co-dependent with on its associated robots), or cooperatively (where it works with other robots as part of a team). The possible architectures are defined below:

Localized: A localized robot has all of its components contained in one "being." It does not have to rely on external devices or robots to carry out its function (may rely on user). A robot with this architecture should be considered *independent* unless it is part of a system or team and can assume any of the previously mentioned morphologies.

Delocalized: A delocalized robot has one or more of its components separate from the main unit, if there is one. The components communicate with each other as they would in a localized architecture, but are simply spread out (see Figure 4.1.11). A robot with this architecture should be considered *independent* unless it is part of a system or team and can usually only assume a functional morphology.

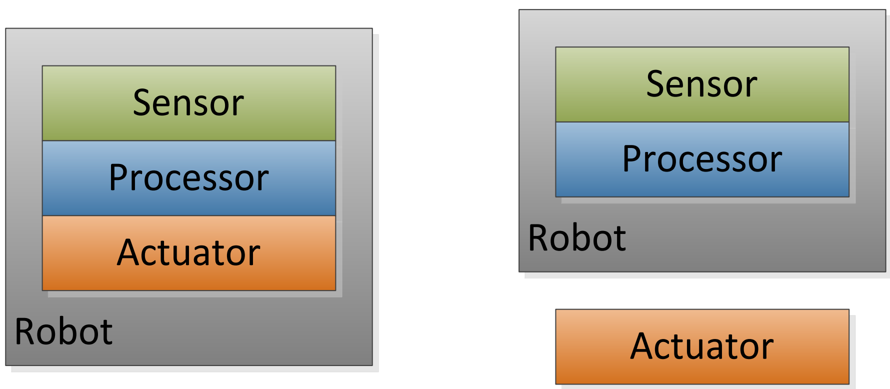


Figure 4.1.11 – Localized (left) vs. Delocalized (right) Architecture

NOTE: Any component can be delocalized, not just the actuator.

Independent: Robot is capable of accomplishing tasks completely on its own, without the assistance of additional robots or devices. It may, however, rely on a human to carry out its task.

Robot System (swarm): A robot system is composed of multiple simplistic robots (limitations in at least one component) that depend on each other or another device to complete a task. The separate robots compliments each other in terms of their sensing, processing, and/or actuating capability (i.e. some robots may have sophisticated sensors but limited actuation, and other may have sophisticated actuation but limited sensing capability). In other words, robots within a system are *co-dependent*, meaning they must cooperate to execute a specific task. In some cases, one component may be shared by the separate robots, i.e. all robots of a system upload and download data from a common server. Robots with this architecture may assume any morphology, although an anthropomorphic morphology is unlikely due to the simplicity of the individual robots in this architecture.

Robot Team: A robot team is composed of at least two localized robots. The robots must be able to operate individually, but in this architecture they cooperate to accomplish a more complex task. Robots with this architecture may assume any morphology.

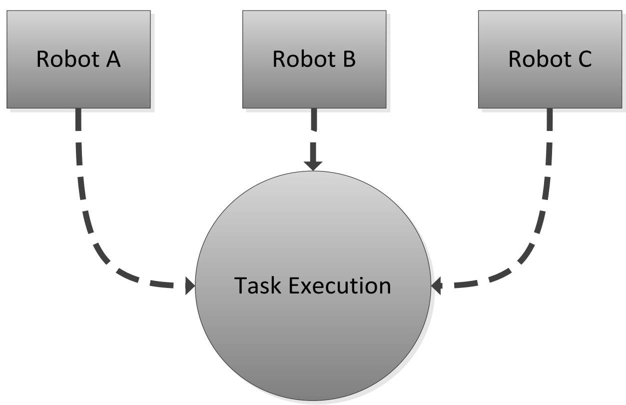
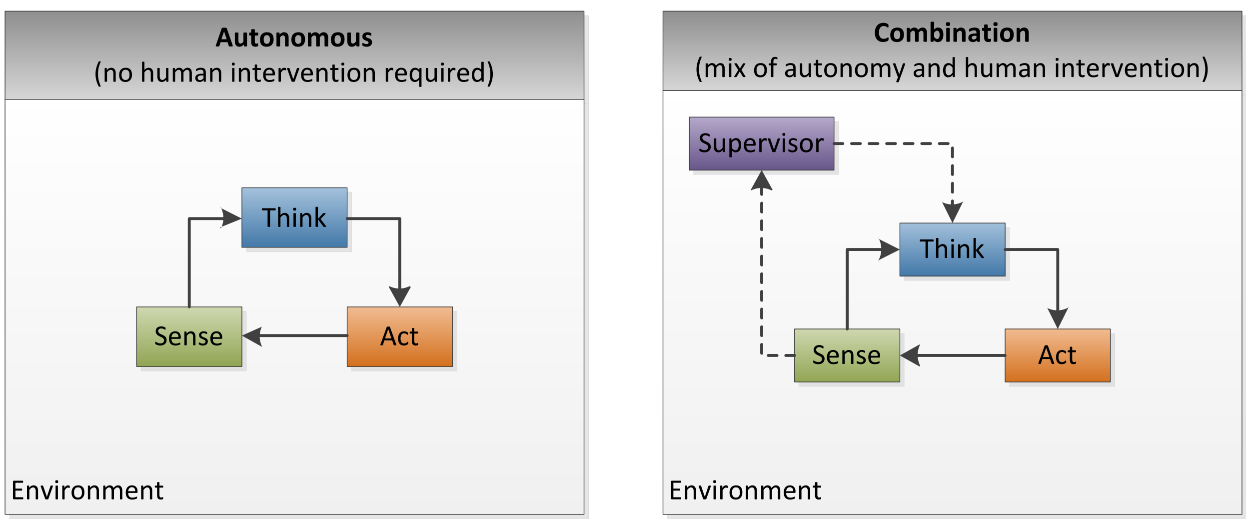


Figure 4.1.12 – Example of Cooperation in a Robot Team

NOTE: All robots are localized and are fully capable of sensing, processing, and actuating the work environment on their own.

Autonomy

With the possible physical structures of a robot characterized, we can now begin to analyze the interaction between the components of a robot, namely its sensing capability, actuating capability, processing capability, and its user- and control-interfaces. We believe that this interaction determines a robot's *autonomy* (actual autonomy depends additionally on the intended function, which may inherently be a limiting factor). We define potential for autonomy as a robot's ability to make decisions and carry out tasks without the need for human intervention. This metric is similar to Yanco and Drury's category in which they relate autonomy and amount of intervention required: autonomy and intervention are inversely proportional; we find it redundant to consider both individually – a low level of autonomy, for example, clearly implies a high level of intervention. Salter et al. [75] developed a loose set of metrics for robot autonomy in their child-robot interaction taxonomy. It is important to note that different levels of autonomy necessitate that the intended users assume certain roles. For example, the lower levels "Wizard of Oz" and "Remote-Controlled" require an operator, and a robot with "Fixed" autonomy requires a commander and supervisor. Highly autonomous robots ("Autonomous" and "Combination") require very limited to no human intervention. This means that the user assumes the role of supervisor or peer, respectively. Robots with "Fixed," "Wizard of Oz," and "Remote-Controlled" levels of autonomy require the user to take on more responsibility as the robot's surrogate intelligence, and assume the role of commander or operator. The different levels of autonomy proposed by Salter et al. are pictured in Figure 4.1.13.



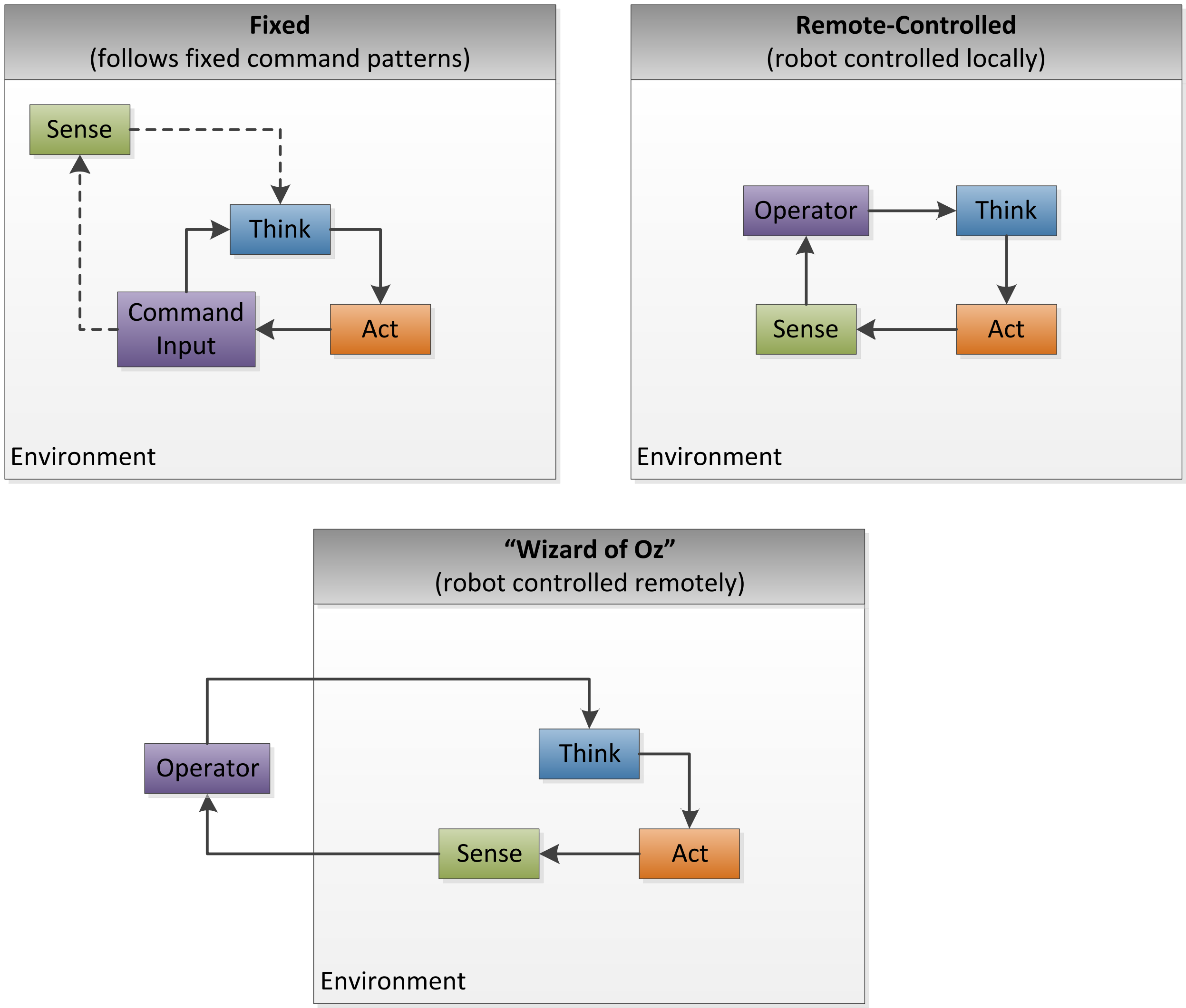


Figure 4.1.13 – Levels of Robot Autonomy

4.1.3 User-Robot Interaction

Having characterized all possible users and robots, it is now appropriate to characterize the interaction of the two. This sort of characterization has already been done, namely by Yanco et al. and Salter et al. in their respective taxonomies. This section aims to organize the different possible interactions between robots and humans, some of which have been mentioned throughout the previous sections.

There are numerous ways in which a user can communicate his/her wants, needs, etc. to a robot, but the user's *intentions* can be summarized as to either control a robot or simply to interact socially with it.

Non-Controlling

The way in which a user interacts with a robot depends on the robot's application, sensors, and actuators as well as any disabilities the user may have. A user can interact with a robot by speech, hand gestures, facial expressions, and tactile input (i.e. pressing a button, flipping a switch, etc.) among others. Conversely, a robot can communicate with its user in equally as many ways: A robot can alert the user with lights and/or noise, synthesize speech and even appearance, provide haptic feedback, or physically interact with the user. This is beneficial because the variety of possible interactions allows robot designers to cater to any special needs their intended users may have. For example, a robot may be capable of recognizing and understanding human speech in order to communicate successfully with a blind user. Direct interaction such as this can be termed *active* interaction, meaning the user is aware and willing to communicate with the robot.

A user may not always be aware that he/she is interacting with a robot, however. Interactions in which a robot is aware of the user's status, but the user is not aware of the interaction, we have termed *passive* interaction. Such interactions are uncommon and are associated with very specific types of robots, namely those intended to monitor or survey a user(s). These types of robots may be very effective in applications related to health care, security, market research, etc.

Controlling

One manner in which a user, particularly an operator, commander, or supervisor, may interact with a robot is to control it, either causing the robot to engage a certain pre-programmed command sequence or controlling the actuators directly. There are several ways in which a user may control a robot. To characterize these different methods, we will borrow Yanco and Drury's space-time taxonomy [77]. As the name implies, the taxonomy categorizes interaction by the location and time in which the communication occurs relative to task execution. The user can interact with a robot either in real-time or in advance, and either locally or remotely. Real-time interaction could be broken down further into the categories *direct control* and *supervisory control*.

The first and most simple method of robot control to be discussed is *real-time direct control*. In this method of control, the user assumes the role of *operator* and directly controls the robot via its control-interface. The operator communicates the desired functions to the robot and they are carried out immediately. Depending on the robot, it can either perform the exact function requested by the operator or augment the command in an attempt to improve or correct it.

Another form of real-time control is supervisory control. This method requires a user assuming the role of supervisor to monitor the robot's performance. The supervisor only interacts with the robot, which in this case is capable of functioning nearly completely on its own, in the event of a malfunction or mistake. When the supervisor does interact and commands the robot to perform a certain function, the robot reacts immediately in order to correct any issues.

The final method for controlling a robot that we will discuss is pre-programming. This method is carried out by a user assuming the role of commander. The commander inputs a series of commands into the robot via its control interface pre-task execution. The robot will execute these commands, often repetitively, at a later time. At the time of task execution, supervisory control will be engaged.

Another way to categorize robot control, as mentioned by Yanco et al., is according to the location of interaction relative to the location of task execution. A robot can be controlled either locally, meaning the controller is in the same environment as the robot, or remotely, meaning the controller is away from the robot at time of task execution. These categories are applicable whether the method of control is direct, supervisory, or pre-programmed.

A robot's control-interface is simply an extension of its user-interface. A controller can interact with the robot by any of the means described in the previous section, namely visually, audibly, or physically. The main distinction between the two types of interactions discussed is the intention of the interaction. Most modern robots require input from a controller, and the ways in which we communicate with technology is continuously evolving. Creating a seamless user experience is extremely important to the acceptance of robots into mainstream consumerism, as evidenced by products such as Apple's iPhone, which is renowned for its convenience and ease-of-use.

4.1.4. Discussion

This taxonomy characterizes both robots and their associated users. With sufficient information about a particular user and his/her needs, preferences, and expectations, the taxonomy can be applied to develop certain guidelines and requirements for a robot intended to be marketed towards said users. The morphology and architecture of a robot are just as vital to its success as its functionality and user interface. Accurately predicting the future of robotics requires a deep understanding of societal perceptions of not only technology, but also of human relationships, productivity, and the role we play as humans in our world.

4.2 Interviews of Industry Experts

We attended RoboBusiness Leadership Summit 2011, held at the Prudential Sheraton hotel in Boston. During the two-day conference, we interviewed contemporary leaders of the robotic industry including Colin Angle, Corey Clothier, Dan Kara, Ted Larsen, Paul McGrath, Erin Rapacki and Thomas Ryden (see Table 4.2.1). The data we obtained was organized by common "themes" such as user's cultural acceptance of robotics, home health care, cost, and insights into robotics trends.

Table 4.2.1 – Basic Information of Industry Experts

Basic Info / Subjects	Position	Years in the industry
Colin Angle	CEO, Co-founder and Chairman of the Board of iRobot Corp.	21
Corey Clothier	Business strategist of the US Army	3
Dan Kara	President of Electra Studios, past-President & founder of Robotics Trends, founder & chairman of RoboBusiness	21
Ted Larson	CEO and Co-founder of OLogic	8
Paul McGrath	Regional sales manager for Maxon Motors	18
Erin Rapacki	Product marketing manager of Adept Technology	10
Thomas Ryden	COO & co-founder of VGo Communications	11

4.2.1 User's Cultural Acceptance of Robotics

As we introduced interview questions in Chapter 3, one of the most important topics we would aimed to investigate was the lack of popularity of robots in United States homes. This lack of popularity may relate to a possible disinterest in purchasing home health care robots for the elderly. All of the interviewees thought lack of interest could be attributed to the cultural background of consumers in America. Unlike in Asian countries, robots have been described as evil destroyers or harmful creatures that can easily get out of control in most robot-related movies. In Asian countries robots have been described as a good friend, companion or sometimes a family member in movies and cartoons:

> *"The US adults haven't grown mature for robotics. We had a culture that thinks of robots as evil, [while people] in Asia think of robots as friendly and helpers, sometimes as heroes. So we have to change, sometime there will be a shift. It will take a little bit of time in the US, from media, movies, the terminators that have infiltrated the adults that people with my age; everyone says we will wonder that if the robots will take over. There's that cultural issue that need to change over time. Next generation*

> *will be able to do that. That's controlling some of the demand." (Corey Clothier, US Army)*

Corey Clothier also had an experience of a pilot project that monitors the elderly in nursing homes. Based on this project, he found that elderly people are perceptive and find humanoid robots adorable: *"[…] humanoid robots, something with personality; I believe they would think [of those as] that kind of adorable and fun companion." (Corey Clothier, US Army)*

He also pointed out another positive attitude of the elderly towards technology talking about Wii: *"What I'm intrigued with is the popularity of the Wii, the video games in nursing homes and elderly care homes. They love playing Wii, so they really like [that] technology." (Corey Clothier, US Army)*

Another interesting point revealed was that most people do not realize how much robots can do for them and how they are being served by many different types of robots/robotic systems. Therefore people underestimate robots and tend to trust human power more. For this issue, it is very important for people who actually understand the markets well enough to see connections and draw big pictures for marketing plans (and for educating consumers). It is also important for the people who understand technology to utilize it in meaningful ways. In other words, we need to match the needs of potential users and today's advanced levels of technology, as emphasized by Paul McGrath:

> *"People still view robotics as a novelty, so we need to make it into a common consumer product to the point where people won't think twice about robots helping your tasks. People still are fascinated by the technology, but it's a bit hard to accept it into everyday life. Nowadays people see more positive impacts of robotics like robotic surgery systems and bomb robots. We know that students involved at younger ages then become the consumers." (Paul McGrath)*

Lastly, most of interviewees mentioned cost as the biggest barrier against the popularity of robots, especially in the home setting. This is discussed in the next section.

4.2.2 Home Health Care

In section 4.2.1, we talked about why robots are not popular in our home. In this section we will talk about home health care in general. The first thing to point out is that home health care is a very challenging field since we have to fit the technology very specifically to consumer's needs. This is not very hard as long as we can apply technologies in the right way and make sure they deliver desired functionalities. However home robots need to be reliable in order to justify a purchase; if they are not, consumers will find other ways to meet these desired functionalities.

> *"The challenge with home health care is first, what you need to do is fairly hard. You need to actually help meet the physical needs of in aging parent or loved one, and you need to do it at a price that can be afforded. If you are only creating solutions that help the wealthy, they have other options; they can hire people to come in and meet the need. You need to do this all at a very aggressive and low cost. So we are talking about a problem that is going to grow over the next 20 years, and we also are talking about a problem that is going to take the next 20 years to solve in a real way. There are lots of steps along the way." (Colin Angle, iRobot)*

One of iRobot's current goals is to develop technology that will help the elderly to live more independently. Roomba, iRobot's vacuum robot fits into that category. According to Colin Angle, one of the most vocal and appreciative demographics of Roomba is the "cleaning-challenged" (e.g. elderly, disabled). The purpose is to make them feel more "house proud" with increased independence. The home health care robots have been readily welcomed by caregivers and health care administrators. Most of the caregivers at home (usually family members) are not "high-tech," or even professionals in the medical field, but they have been receptive of robots that can reduce their workload and help improve efficiency. Many potential users have just not had enough experience with robots to understand how robots can actually help them. The health care administrators and even regulatory authorities could be very open and interested as well, since it is very true that robots can often provide cost-saving solutions with high quality of care, as Clothier mentions:

> *"Administrators would be very interested because this would be a cost saver, and they could provide better care. That's why I've been using*

> *[this] technology in my facility because I could actually provide safer and better care for a lower cost." (Corey Clothier, US Army)*

Continuing the support for elder care robots, Erin Rapacki predicted that *"the first robot in our home will be an elder care robot for people who want to stay home with privacy by spending couple thousand dollars instead of going to a nursing home." (Erin Rapacki, Adept)*

She pointed out that the elderly often need help in their home, and that a living-assistant system or robot could be especially useful for this situation. She mentioned specific technologies that could be applied, such as voice recognition systems and object-recognition systems for the users (elderly).

The interviews also helped us to understand the challenge of health care robots in the home, as opposed to health care robots in the hospital or other professional settings. First of all, the functionalities necessary for consumers are very different that these other settings. For the medical industry, many companies receive investments and funds from the government. It is worth noting that the robots in hospitals have to be relatively more precise and accurate performance-wise than home health care robots.

> *"Home health care isn't driven as much by cost, but more by [the robot's] applications and capability. […] Prosthetics are very expensive but with recent advances, you can get devices that do a great job for the patients." (Thomas Ryden, VGo Communications)*

In addition, home robots need to have the sensor capability to navigate the house and deal with a typical "home setting" (relatively not organized as hospital or other professional environment), but with less maintenance. This is because users want, and even expect the robot to clean the floor at least close to the same degree as a human would. In hospitals, however, robots are well maintained by hospital technicians and have better working environment than home robots do.

4.2.3 Cost

> *"Everyone wants their robot to be cheap. If you look at the market research for consumer robotics, it says that the average price a typical*

> *person is willing to pay for a robot is $300. It doesn't matter if it's ASIMO; people aren't going to pay more than $300 for it." (Ted Larson, OLogic)*

As we discussed in the previous section, home health care robotics is largely cost-driven. Therefore we can say it is a field of "consumer-facing" robots. Ted Larson's OLogic was the only consumer-robot company that attended the RoboBusiness conference. As seen earlier, based on research OLogic conducted in the consumer robotics market, the average price a typical person is willing to pay for a robot is $300. According to Larson, robotic products entering the market of consumer-facing robotics with an affordable price are very rare because it is very hard to deliver what user wants (reliability, endurance, maintenance, and so on) within the cost constraints in consumer robotics.

> *"Most people in robotics spend more time engineering to solve the problem with whatever technology is available, regardless of cost." (Ted Larson, OLogic)*

Based on quantitative research done to determine factors holding consumer robotics back from getting into homes, Dan Kara views cost as a primary barrier. Another such barrier is people's doubt about the functionality the robot will deliver. Kara used the Roomba as an example: *"It doesn't have to work as good; it just has to work as advertised. Roomba is not as good as a human, but you don't have to vacuum every day." (Dan Kara, Electra Studios)* In other words, even if the functionality is not as good as the user desires, they would still purchase such a robot if it could deliver that "lesser" functionality for a practical cost.

4.2.4 Insight in Robotics Trends

The team was able to investigate the industry experts' opinions about what area of the health care industry is growing most rapidly. Many also provided additional thoughts and concerns about potential problems in today's robotics industry, including government policies and industry issues.

All of the interviewees mentioned prosthetics and rehabilitation as the most promising and rapidly growing areas. Colin Angle and Thomas Ryden mentioned iWalk and DEKA technology as examples how that field has become very large in current markets.

Prosthetics is conventionally a promising area since government and military departments invest a lot of resources into the field. Paul McGrath mentioned some prosthetics applications such as artificial limbs, and how they have recently made major advancements. Ryden elaborates on the growth of prosthetics, *"Full exoskeletons allow 'replacement' of damaged areas of the body and can assist soldiers." (Thomas Ryden, VGo Communications)* Rehabilitation is also a recently improved area in the field of robotics and medical technology. DEKA technology's robot assisted device that helps patients to recover from strokes is the biggest product in the industry right now. Additionally, rehabilitation robots have an incredibly huge population of potential consumers. According to Dan Kara, more than 700,000 people in the United States have strokes per year and most of them need continuous monitoring over time. In addition, the rehabilitation process takes place in home settings, rehabilitation centers, or hospitals. This indicates that home health care robots will have a chance to grow quickly by combining and integrating with rehabilitation robots.

4.3 Focus Groups

In order to learn more about different people's perceptions and expectations of robots, we decided that it would be appropriate to conduct focus groups. We chose to conduct a total of three focus groups: two on campus at WPI and one at Summit Eldercare, a local alternative to nursing homes. We selected participants from two distinct demographics, the first being college students at WPI (potential future care-givers) and the second being the elderly that attend Summit Eldercare in Worcester. The results we obtained from each focus group is discussed in the following sections.

4.3.1 WPI Focus Group 1

The first focus group the IQP team performed involved five WPI students (two males, three females, age 18-25). Further details about the participants can be seen in Table 4.3.1. In general, this study investigated the broad opinions of the participants concerning technology, privacy, and robotic autonomy. Because it was the team's first focus group, many of the results were more broad than desired. The results still provided insight into some of the target topics, however, and gave the team a starting point from which to plan later focus groups.

Table 4.3.1 – Basic Information of 5 Interview Subjects for First WPI Focus Group.

Basic Info / Subjects	Age	Gender	Role at WPI	Field
Subject 1	18-25	F	Student	Management, Theater
Subject 2	18-25	M	Student	Robotics Engineering
Subject 3	18-25	F	Student	Civil Engineering
Subject 4	18-25	F	Student	Chemical Engineering
Subject 5	18-25	M	Student	Chemical Engineering

Ethics

Much of the first focus group revolved around the ethics of robotics and the implications of advanced technology. The participants were uneasy when it came to "roaming" robots. Regardless of whether or not they were used for monitoring, chores, or assistance, these robots could be perceived as a threat to their privacy.

Another popular, yet very broad topic was what the IQP team calls the "role of humans". This category addresses the issues that arise as humans give up certain obligations or responsibilities to artificial intelligence and robots. One participant in the focus group brought up self-driving cars as one example of how the role of humans could be lessened in the future. Another participant felt that having robots replace many of their roles, whether trivial or not, could make them feel useless rather than assisted. Although having a robotic assistant would eliminate many of the negative variables of human interaction (greed, emotions, mistakes), it would also mean that the vast array of benefits that stem from human interaction would be lost. In the end, participants thought that the personal connection was something that should never be lost entirely, especially when it came to elder care. In fact, one participant hypothesized that future products that reduce the role of humans would not see much success, for just these reasons. Additionally, a common question that arose during this discussion was the following: Though machines and computers tend to provide some benefits that humans can't, how much control or influence do we want to allow them to have? For the team, it's important to have a good idea of the target demographic's answer to this question, as it will allow us to specify the robot's degree of independence in order to cater to that demographic's desires. However, there is no one answer, as the degree of control people are willing to relinquish depends on many variables, such as lifestyle, culture, and moral beliefs.

The general perception of robots and all technology people have was another major topic of conversation over the course of the focus group. Despite the more recent practical uses of robots in tasks such as bomb defusal or surgery, the group agreed that public perception of robots and artificial intelligence (AI) was largely negative. From an unspecified USA Today article, Subject 2 read that *"people are becoming more and more concerned with how autonomous some of these [robots] are."* Subject 1 responded with her opinion:

> *"I don't think [the general population is] afraid of robots the way they are now, I think they're afraid of what they might become...they're afraid of a snowball effect. And I think a lot of it is because of the way that [robots] have been portrayed in media like the film I, Robot."*

In popular media like this, robots are often portrayed as a runaway, highly intelligent robot with no moral compass. Subject 2 pointed out that as robots are made to be *"more autonomous and more intelligent-seeming, suddenly the robot becomes capable of human-like [actions] without necessarily having human emotions or human morals, and that makes people uncomfortable."* So we see that the perception of robots really depends on how threatening robots seem, which is heavily influenced by their autonomous capability; if robots are too close to mimicking humans, people are extremely wary of accepting them.

Although many robots today are partially controlled by humans, many people may not know or understand this. Instead, they think of autonomous robots as far smarter than possible. During this discussion, a member of the IQP team asked whether the participants thought that their generation (Generation Y, typically born in the late 1980s and 1990s) would be more accepting of robots and AI. One participant still wasn't hopeful for the future acceptance of robots, saying that it depends on how threatening they seem and how complex they become. Subject 1, however, thought that *"as the idea of [independent robots] is introduced more and more, people will become more comfortable with it."* From these results, it is not far-fetched to say that even as Generation Y ages, opinions will be split over the acceptance and usefulness of robots.

Function

While this initial focus group's discussion centered much more on the acceptance and perception of robots, AI, and technology in general, there were a few instances where desired functionality was touched upon.

As could be predicted from their ideas concerning the "role of humans", the focus group participants thought that assistance was one of the best applications of robots. According to the participants, the most useful and acceptable assistance robots would be ones that performed difficult or menial tasks, not ones that replaced integral human actions. One such example is iRobot's Roomba. As Subject 2 pointed out, *"it takes on a fairly undesirable task (vacuuming), and does it well."*

The participants were wary of monitoring robots, mostly due to privacy issues. These views were highlighted in the earlier *Ethics* section, but in general, these students thought that if robots emulated humans too well, or invaded their privacy, many potential users would be turned off. The IQP team did not have a chance to introduce eNeighbor, however; as a non-intrusive, dispersed, home monitoring system, eNeighbor may have given the participants a new angle on the monitoring functionality. This home monitoring system was used in later focus groups to demonstrate the monitoring capabilities of smart health care.

Participants seemed fairly opposed to robots as companions; Subjects 1 and 3 agreed that the elderly may *"want something to do [chores] for them, but they still want human contact and interaction."* In earlier discussions, however, at least one of the participants suggested that robots could make decent companions, under certain conditions. Though they may never replace humans entirely, as AI advances, robots could become more personable and easy to interact with. Even today, without superb AI, many people can become emotionally attached to their "inanimate" robotic assistant. This shows that at least some potential users believe it is possible for robots to provide a basic form of companionship, though these kinds of robots would not be able to replace human companionship, at least in the near future.

The functionality is where the acceptance starts, but cost also plays a big part in the adoption and popularization of such robots. The perceived value of the robot (a combination of functionality and cost) was another aspect the focus group discussed. One participant (Subject 1) suggested that it is mostly curiosity that drives current sales, as many robots are too expensive or not useful enough to justify purchases. VGo, a telepresence robot on sale for $6000 is one example of such a robot. The mobile platform with 2-way audio/video was not enough for the participants to justify a purchase. The Roomba, on the other hand, is only a few hundred dollars, and eliminates a common household chore from users' to-do lists; participants thought the Roomba was a good example of a well-balanced value.

All functionalities have some kind of constraints associated with them, either due to technical deficiency or desired limits from the potential user. One constraint that the focus group participants pointed out was the responsibility of robots; are these autonomous devices ready to monitor vitals, dispense medicine or other critical tasks? The privacy issue that accompanies the implementation of roaming and/or monitoring robots is another constraint that the participants (especially Subject 3) thought was important to consider, no matter the situation.

Overall, participants were adamant that perception could indeed be influenced by the appearance of robots, as well as popular media, such as television and movies. On the whole, we can see that students in this first focus group were in favor of assistance robots – those robots designed to ease simple burdens, while still remaining cost-effective. Participants were wary, however, when it came to privacy issues surrounding more intelligent and capable robots. This study helped lead us to the conclusion that even for those of Generation Y, a very technologically-oriented demographic, it is common to be uncomfortable around robots that adapt the role of humans too readily, either by adopting their appearance, or taking on more complex tasks/"thoughts".

4.3.2 WPI Focus Group 2

The second WPI focus group involved four WPI students (three males, one female, age 18-25) and one WPI employee (female, age 25-35). More details can be seen in Table 4.3.2.

This study, a refined version of the first WPI focus group, was able to collect more functionality information, in addition to general opinions concerning the ethics of robotics and technology.

Table 4.3.2 – Basic Information of 5 Interview Subjects for Second WPI Focus Group

Basic Info / Subjects	Age	Gender	Role at WPI	Field
Subject 1	18-25	M	Student	Robotics Engineering
Subject 2	18-25	M	Student	Computer Science
Subject 3	18-25	M	Student	Robotics Engineering
Subject 4	18-25	F	Student	Management Engineering
Subject 5	25-35	F	Employee	Computer Science

Ethics

Though ethics were a concern for this second focus group, the participants were more accepting of a possible lack of privacy than the first focus group, depending on the situation. Subject 2 pointed out that the robot itself *"doesn't care about the collected information; it depends on who is receiving the information and how they're treating it"* (in a monitoring system for example). Subject 5 added that users *"may not understand that the robot isn't doing anything with the collected information,"* they just know the information has been collected. Others agreed that if the data is communicated to an outside source, whether it is a database or a human, the issue of information security arises. Keeping sensitive data secure is something the IQP team would have to keep in mind if designing some form of monitoring robot. A service like Facebook, however, indicates that many people (especially in younger generations) are not always concerned about their privacy. Additionally, the functionality an information-collecting robot provides could outweigh the potential privacy drawbacks. When eNeighbor, the home monitoring system, was introduced to the focus group, the team received mixed responses. Some of the participants, such as Subject 5, said they *"wouldn't want to know this* *much information"* about their loved ones, and were concerned about an invasion of privacy or leak of sensitive information. On the other hand, Subject 1 noted eNeighbor's potential for increasing an elderly person's independence, stating that it could help bridge the gap *"between living independently and moving to a nursing home."* eNeighbor could also give both the caregiver and elderly a stronger sense of security.

When asked about the replacement of humans in certain tasks, the second focus group largely echoed the first, agreeing that certain aspects of the role of humans could never be truly replaced. A self-driving car, Subject 4 said, lacks the *"human element and judgment"* that may be impossible to translate to programs. While something simple like the Roomba provides no real threat to the role of humans, participants were adamant that companionship is one of several examples of an irreplaceable human role. Furthermore, as Subject 1 highlighted:

> *"[It's unlikely] that there will ever be a 'one-size-fits-all' system; [the robot] needs to be tailored to the problem at hand."*

Indeed, many user's situations overlap with others, and all need care and attention in order to actually provide benefit when dealing with the problem at hand.

In general, the focus group participants agreed that many people perceive highly sophisticated robotics and AI with suspicion. When it comes to simpler, more controllable robots, however, much wider acceptance can be seen. In fact, the simpler a robot gets, the less like a robot it appears, which may contribute to a better perception of that robot. Again, Roomba is a perfect example of this: small, controllable, non-threatening, and almost never marketed as a robot but an automated appliance. With these ideas in mind, the focus group and IQP team hypothesized that two major variables controlled the perception and acceptance of robots (at least from an ethics point of view) – degree of control and degree of autonomy.

Function

The discussion in this second focus group was purposely aimed more at extracting participants' opinions of the example robots. The IQP team also looked more actively for suggestions for which type of robot would be most desirable for the participants or their family members. Because of this, the second focus group yielded more unified, in-depth results than the first focus group.

This second focus group determined that the potential applications of assistance robots were vast and varied, even for the elderly. As a home assistant, robots could aid those who are unable to complete tasks alone, such as dressing, cooking, or washing. Such robots could also help people who are unaware that tasks must be completed (those with dulled senses), such as automatic laundry or dusting. At least one participant, Subject 3, believed that a pill-dispensing robot would be the most beneficial application of a basic assistance robot, and would be *"the easiest to convince people to adopt"* due to its straightforward yet useful purpose. It is true that pill schedules can often be overwhelming or confusing, especially for the elderly patients taking them. In general, the focus group participants believed that having automated appliances spread throughout the home, designed to make daily living easier would be the best assistance-based solution. This system would certainly help the disabled and the elderly to raise their standard of living, and to live independently as much as possible.

The participants in the second focus group thought that monitoring would be another useful, feasible application for a robot or robotic system. No matter the specifics, the participants agreed that a monitoring robot would be a great way to check in with elderly family members, and increase their ability to age in place. One such robot could follow the dispersed-system approach, with various sensors around the living space, designed to pick up on atypical behavior. This device, much like eNeighbor, could *"make the elderly feel safer in their homes,"* and provide peace of mind for relatives that is not possible with phone calls or technology like Life Alert. Participants also suggested that a pill-dispensing robot could fit in the monitoring category, by determining the health of the patient, and adapting to their schedule. Privacy, as discussed earlier, was a concern in these kinds of applications, at least for the participants. However, participants were confident that if the information was carefully protected and distributed, there would be no privacy issues. A final thought from Subject 4 pointed out that we will likely have a *"'smart house' [an interconnected system of appliances or sensors] sooner than a companion or free-roaming [single-unit robot]."* Many of the components for such a system are already in place, and the fast growth and emphasis on interconnection of today's technology will only draw the arrival of such systems closer.

The focus group was less optimistic about the possibilities of companionship robots. The automated appliances discussed earlier definitely would lack a personal companionship aspect. Overall, the participants figured that robots wouldn't be able to replace the emotional connection that humans provide. However, Subject 5 quipped that *"the kids have named it,"* referring to their household Roomba, so perhaps there is something to be said for pet-like companionship in a robot.

The perceived value of a robot definitely plays a role in their acceptance and adoption rates. As robots are now, many people (especially the elderly) are reluctant to invest a significant amount of money into something that may not provide the kind of benefits they were looking for. A few of the participants agreed that if it were possible to remove the price tag from robots, people would be much more likely to try and like them. Subject 5, the most business-oriented of the participants, gave the advice that since:

> *"Many elderly are on fixed or no income [...] whatever you come up with, you need to make sure health care companies accept it and are willing to pay for it for some people."*

Therefore, if certain health care robots could be covered by insurance, such as Medicare, they would likely be far more successful than otherwise, or at least have a better chance of adoption in today's skeptical markets.

By the end of the focus group, it was apparent that any sort of robot would have to have some constraints to make it acceptable into the home and lives of loved ones. One strong point the participants brought up was the connection between user-friendliness and acceptance. Many of the students' grandparents are not technologically savvy, and may never come to accept new technologies. Instead, the baby boomer generation and younger generations are likely to adopt such technologies; by the time these generations need such assistance, the technologies may even be advanced enough to provide a true boost to independence and standard of living.

When it came to ethical issues surrounding robots, the second WPI focus group was more concerned with privacy than anything else. Robots with free-roaming design or information-collection purposes were seen as the biggest threats to privacy. While the team does not want to eliminate these options entirely, we understand that the design for such robots must be a cautious one. The participants in the second focus group echoed the thoughts of the first focus group; robots to assist with minor tasks could be the most practical and useful application of robotics using the technology as it exists today.

4.3.3 Summit ElderCare Focus Group

Summit ElderCare contributed to the IQP team's research with much valuable first-hand data from the primary demographic of the project. The study investigated the opinions and feelings of the elderly regarding the culture, cost, and functionality of robots and other smart health care devices. It also led the team to better understand the needs, desires, and lives of the elderly, which turned out to be very different from the team's original expectations. The data gathered from the Summit ElderCare focus group showed perspectives that were distinctly different from the previous two WPI focus groups.

Background Information

There were 7 participants in the Summit ElderCare focus group. Before we started the project, the team members talked with the elderly about their lives and other basic background information, which gave us some initial insight into the participant's lifestyles. Tables 4.3.3 and 4.3.4 provide some relevant background information collected about the subjects.

Table 4.3.3 – Basic Information of focus group subjects.

Basic Info / **Subjects**	**Age**	**Background notes**
Female subject 1	>80	Lives with daughter, son comes over to Summit ElderCare 2x/week
Male subject 1	65-80	Lives with daughter, female caregiver 1
Male subject 2	65-80	Lives alone with hired aide
Male subject 3	>80	Legally blind, lives with female caregiver 2 and male caregiver 1
Female caregiver 1	50-65	Cares for male subject 1
Female caregiver 2	50-65	Caregivers of a legally blind elderly relative, male subject 3
Male caregiver 1	50-65	

Table 4.3.4 – Daily difficulties and help needed.

Basic Info / Subjects	Help source	Difficulty	Tasks they (need) help with
Female subject 1	Daughter	Unexpected fall	Meals, clothes, washing. Not allowed to do tasks alone.
Male subject 1	Daughter	--	--
Male subject 2	Hired aid	Handicapped for three years. Falling 5-6 times a year.	Vacuuming, cleaning, cooking, dressing, showering
Male subject 3	Daughter, son-in-law	Legally blind	--
Female caregiver 1	--	--	--
Female caregiver 2	--	--	Help elderly dressing (socks, buttons), breakfast, shower, supper
Male caregiver 1			

Most elderly participants attend Summit ElderCare a few times a week during the day, depending on their personal need. The majority are picked up by the Summit ElderCare van in the morning, and return home with a family member after lunch or in the afternoon. Generally speaking, most participants live within an hour drive from the facility.

Life at Summit ElderCare

The team took note of some activities and daily procedures that the elderly would do during their day at Summit ElderCare. The activities provided at the facility are very interactive, and include stories, games, conversations (such as questions and answers), and exercises. Other daily procedures include reading and some writing puzzles. In general, Summit ElderCare always keeps participants busy, and engages these participants in many various activities to help keep them mentally awake and emotionally fulfilled.

Participants generally liked the interaction and communication promoted at Summit ElderCare. The opportunity to get out of their homes and find something to do also effectively reduced loneliness and depression. Moreover, Summit ElderCare's quick and attentive medical care ensures their health and gives participants, caregivers, and family a greater feeling of security.

Ethics

The discussion brought to light many insights dealing with acceptance, such as privacy and independence, which had previously been considered barriers for the acceptance of robots. In general, neither elderly nor caregivers had strong negative emotions toward robots, and they were confident that robots could fulfill certain roles. However, participants were not accepting of the notion that robotics may soon aim to replace humans in companionship or personal caregiver roles.

There was a distinct mindset regarding the privacy of the elderly. In previous focus groups, younger generations had privacy concerns for secure data storage for monitoring and information-tracking robotic systems. However, it turned out that the elderly would welcome anything that may improve their safety and quality of life, including monitoring systems, as they certainly understand and feel the need to have someone or some machine to keep an eye on them.

From the focus group, we could see that the elderly would not mind doctor checkups at all; they actually viewed them in a positive way. So we followed up with the question: *"Are you comfortable with these kinds of sensors in your home? Or is it violating your privacy? Or maybe you feel it's protecting you?"*

The male caregiver proposed it was fine to use in his mother-in-law's home. He himself was also reaching the elderly demographic, but he didn't view privacy as a serious issue.

The second female subject put it more clearly: *"To me, that would be a good thing. I don't think it's invading privacy, not when it's someone who does need help, and could need you in the middle of the night or day."*

Aware of the contrast between the attitude towards privacy of WPI students and the elderly, the second female caregiver answered our doubt by suggesting young people visit the elderly more frequently to quell their fears surrounding these privacy issues:

> *"[Those concerned with privacy should] ride the vans and do everything that is done for these people [Summit ElderCare participants], and they wouldn't worry about privacy anymore. It's for their lives."*

Besides privacy, the elderly would like to enjoy their independence as long as possible, sometimes even to the point where their family may become worried about their safety. So a robot that could both maximize participants' independence while also providing a form of safety could be in high demand for this demographic. The elderly, their families, and caregivers would certainly be happy to see that robot come to market. But no matter how independent they want to be, the elderly know they need to be taken care of by their families and professionals.

Female subject 1, who came to Summit ElderCare because she couldn't get up after an unexpected fall, knew her problem well. She liked to do tasks by herself and tried to help her daughter as much as she could but was not allowed. When she was asked *"if your daughter could keep an eye on her, but wasn't there, would that just be as good?"* She gave an honest answer: *"Somebody has to be there at all times with me; I fall too much."*

Male subject 2, who has been handicapped for three years, agreed by adding "*without anybody at home, I could never do anything."* He had hard time walking but had been improving over time, from the help of a crane and walker, now using a wheelchair (mainly for the bus). Falling was also one of his concerns. He fell 5-6 times in the last year, which could have been a huge problem if he was living alone.

Hence, human relationships play a critical role in the lives of the elderly, which introduces the companionship topic. No matter how sophisticated or advanced a robot seemed, the participants would always prefer human relationships. Participants maintained that robots could not replace humans completely, though they may be able to offer emotional support in some way. Some participants were concerned that robots could affect or replace their relationship with other people. Male subject 2 stated that he would prefer to come to Summit ElderCare for human communication and interaction rather than live with a robot companion all by himself. Though the participants didn't think highly of robots taking on the role of humans, a few thought robots simulating pets would be more acceptable. The cost of a robot and the design of the robot were two of the main concerns regarding companion robots. If the cost turned out to be more than a certain level, people would prefer paying for a pet sitter rather than spending a large amount of money on a robot companion. It would be tough to market a both cost effective and satisfying design for such a personal robotic companion.

When Paro was presented as the robot for companionship, female subject 2 thought it was almost creepy. She also mentioned that she would prefer a different design, such as a dog instead of a seal. When participants were asked about their preference between Paro or real animals, the third male subject answered:

> *"It depends on person who is using [Paro] and their abilities. If they've got all their faculties, it may not do much for them. For somebody with serious dementia, it may [work well]."* As for the cost constraint, female subject 1 argued that *"I couldn't spend $4500 on that...I could pay a pet sitter full time to take care of a pet for less than that."*

It seemed that companionship robots didn't get much praise from the participants that day. The next robot presented was VGo, the monitoring robot which could serve the other end of companionship spectrum from Paro, due to the easy access of visual and audio communication. The participants were asked if they thought VGo could be a good replacement for visits to or from caregivers, family, and friends. The male caregiver felt it would work if the caregivers were the ones controlling the robot in the elderly's home, rather than giving the elderly person control.

The focus group participants suggested robots that could provide simple interactive games. Female caregiver 1 mentioned that designing a robot to play *"simple games of rummy [would be] legitimate"* and that *"most seniors do some type of puzzle daily"*. She pointed out that the robots or games should be user friendly, especially due to her recent difficult experience with setting up a Microsoft Kinect for use with her father.

Functionality

When the IQP team moved on to discuss functionality, there was a point made about the constraints for current robots in not being able to consider the needs for the disabled; the potential market for the handicapped or people with special needs would be huge.

Additionally, there has not been a single design in the market that could fit the needs of most users.

Some of the functionalities suggested by female caregiver 1 included checking vitals and sending information to Summit ElderCare before participants arrive. This would keep a better record of tracking participants' health conditions, and provide better quality of data for nurses and doctors. Pill dispensers or task reminders reminding the elderly to take the correct pills regularly would also be really helpful, according to this female caregiver. In fact, female subject 1 answered her daughter's phone call during the focus group, in which her daughter asked the subject her everyday question: had she taken her pills for the day?

Other suggested functionalities included performing eye drops or administering medicine that the elderly would normally find difficult. There was also a need for those with arthritis; a robot which combined strength and dexterity could make up for inflexible human hands. Specific tasks such as dressing, putting on socks, and buttoning clothing has been a headache for many of the focus group participants.

Female caregiver 2 suggested a robot could aid or monitor the elderly for the time they were not at the facility, since she was confident that Summit ElderCare already provided the necessary essential care. For example, the robot could assist in dressing, breakfast preparation, or showering before departure for the facility.

In favor of monitoring robots, participants thought the ability to check vital information and send this collected data to a doctor or caregiver would be very useful. According to caregivers, robots that could monitor the time when the elderly took their medication would be extremely helpful. Female caregiver 1 added that *"machines giving medication wouldn't diminish independence much"* and *"would give more time for interaction and other activities"*. These thoughts revealed a distinct need for intelligent medication dispensers.

The eNeighbor monitoring system showed to participants during presentation received positive feedback. Female subject 1 uses Lifeline, a similar product, though less advanced than eNeighbor. The male caregiver thought monitoring systems could be beneficial, adding, *"it is important to know when Alzheimer's patients are on the move"*. All the caregivers agreed the monitoring system would be a great backup and help put their minds at ease, even if someone was still living with the elderly patient. As female caregiver 1 pointed out, a monitoring robot could provide a realistic solution for a reasonable price. After the focus group, though group was surprised to learn from the site director Ms. Salisbury about Summit ElderCare's interest and new involvement with eNeighbor. Summit ElderCare would like to better track the health of its participants when off-site, making eNeighbor an optimal solution.

Rehabilitation robots are currently effective in helping with strength and dexterity (especially for arthritis) and they can be extremely useful for walking or steadiness. Some good feedback was received for the Toyota Healthcare robots, which helped people with walking or movement difficulty among other tasks. Male subject 2 said: *"with the help of wheelchairs and walkers, machines can improve the situation a lot, but [many people would] still need someone to help, even with a machine."* Female caregiver 2 added that such a robot may mitigate the difficulty of picking up dropped items. Then she pointed out that robots could never replace tender loving care with their help. Her opinion drove back to the companionship issue, but she proposed a new idea of the combination of human and robot aid. Even with the assistive robots, the personal components should still be addressed by a human.

Regarding assistance robots, the caregivers explained their roles in preparing meals, helping out with dressing (especially socks and buttons), showering, laundry, cleaning, walking, and other daily tasks. Taking medicine or reading difficulty were also areas in which the elderly may need help. Roomba, the robot that performs housekeeping tasks, was questioned by male subject 2, as it might not work well with some living spaces or crowded places with furniture. This participant currently receives all cleaning and other services from hired help, which would be tough to replace with assistance robots, much less a single Roomba.

To speak of robots in total, Paro and VGo seemed to be too expensive for the elderly. Companionship robots also received largely negative responses, due to the fact that human care would be nearly impossible to accurately replicate and replace with today's technology. Instead, participants would prefer robots that provide affordable and realistic (yet still beneficial) services like eNeighbor.

In the end, we held an open discussion for any robot that would be their favorite regardless of cost. Their opinions are listed below.

- Female subject 1: something to clean
- Male caregiver 1: depends on the needs; nothing would cover everyone's needs, so it would be an individual decision
- Female caregiver 1: *"If I were you, and I were designing this, I would shift totally toward the actual **informational side** of things. If you take away the human contact, then you're not going to need any of the rest, so you're spending money in a way that isn't going to matter."*
- Male subject 2: caregiver tries to prevent entry into nursing home for as long as possible, and eNeighbor could do help with that
- Others: physical assistance to prevent falling
- Elderly want independence, but caregivers and families gain anxiety from giving that independence; human interaction is complicated but allows for this independence.
- From team member: A more integrated and holistic system with a more proactive approach to monitoring health could diagnose diseases & problems at much earlier stages, and increase quality of life.

Summary

Independence was what the elderly were looking for as long as safety was guaranteed. Privacy didn't seem to be a big issue, as safety was their main priority. The elderly and their caregivers often need assistance for daily living activities and tasks. The human aspect of care-giving was particularly important to the participants, as they cherish their relationships and interaction with the community; this opinion shows a distinct barrier for the acceptance of companion robots. Overall, the team believes that monitoring robotic systems have the greatest potential, especially because they could send their collected vitality data to physicians, which could greatly benefit the elderly through emergency response and early diagnosis.

5 Discussion and Recommendations

The major goal of this project was to identify a set of requirements that could guide the design of a personal health care robot. In order to arrive at these requirements, the team considered many aspects of how such a robot would function and meet the end user's needs. These considerations were derived from the team's interpretation of their background research and study results. The primary considerations the team investigated were functionality, acceptance, convenience, and price; these are discussed in the following sections. The ideas brought forth in the analysis of these considerations were synthesized into a number of distinct requirements for a personal health care robot for the elderly.

5.1 Considerations

The analysis of the various factors we considered in our research and studies represents a summation of the major ideas generated by the team over the course of the project. By discussing and refining these considerations, the team was able to develop of a set of user requirements for a home health care robot for the elderly. Such a robot must:

- Allow for independent living;
- Provide support in case of emergency;
- Provide valuable diagnostic data;
- Have an intuitive user interface;
- Appear as a non-threatening device;
- Be financially feasible.

5.1.1 Functionality

An ideal health care robot intended for elderly care would be capable of all the many functionalities that such existing robots commonly exhibit, i.e. home care, monitoring, rehabilitation/mobility, and companionship. However, such a robot would likely be too expensive for the average consumer due to technological limitations. Additionally, consumers will not generally pay for additional functionality they don't necessarily need. A personal health care robot must be customizable to individual user's wants and needs. This can be achieved by providing several different products with different functionalities that can be integrated with each other and meet the needs of the user. The purpose of this project, however, is to identify the ideal application of robotics in personal health care. Therefore, we must narrow down the options and select an appropriate functionality.

5.1.2 Independent Living and Security

Many members of the elderly demographic (ages 65+) prefer to age in place, meaning they hope to remain independent enough to stay in their current living situation. This desire to live independently at home is good news for the health care industry – if some method could be developed to help the elderly remain in their homes longer, it would mean less populated nursing homes as well as hospitals. Much of the appeal of living independently is not in living alone, but in being able to accomplish tasks without the assistance of others. While taking over these tasks could improve the quality of life for a user, monopolizing them could reduce that user's feeling of independence and self-worth. A robot that is designed to respect this desire for independence could therefore be a popular device. It could allow independence of the user by taking over a limited, specified number of tasks; or more simply, it could not assist with any tasks, instead fulfilling other needs. A monitoring robot, for example, could provide the user, their loved ones, and their caregivers a sense of security while still allowing full independence.

5.1.3 Convenience

In addition to security and independence, the robot must provide a certain level of convenience to the user. From the focus groups we conducted, we identified ease-of-use as a significant concern of elderly individuals. The user interface of a device must be simple enough to navigate and use effectively. Intuitive user-interfaces, capable of "learning" the user's preferences and habits and applying it in the user interface to create a more seamless experience (i.e. Google Search), are ideal because they interact with the user in a more personal way and require less input.

5.1.4 Price

Even once the demands and needs of the user and the target market have been met, price can still hold back adoption and subsequent success of the product. Robots are no exception to this rule, especially considering the high cost of their design, components, and production. Developing complicated systems of robots or robots that perform multiple tasks can further inflate their already high price. Like most cutting-edge technology, robotic products have to balance their price appropriately, so that investment is feasible for both the producer and the consumer. While cost reduction on the business/industry side was outside the scope of this project, the team did study the responses of focus group participants to get an idea of the potential users' opinions on the price of various robots. Overall, the responses depended heavily on the perceived value of the robot. If a robotic device could not provide a certain desired functionality or improve quality of life in some way while still maintaining a relatively cheap price, the participants said they would not purchase it. This opinion is supported by research done at OLogic, where they found that customers were not willing to pay more than $300 for a robot, regardless of its features. So we see that price is tied very strongly to the other considerations discussed earlier. One way to deal with these tight cost constraints could be through insurance coverage. As a medical device, a home health care robot could be a potential candidate for such coverage. This would reduce the price barrier significantly, encouraging adoption of the robotic health care product that may not have happened otherwise.

5.1.5 Proactive and Reactive Care

There is another issue that our design should be required to solve. It is the skyrocketing health care demand resulting in hospital and nursing home overcrowding due to an aging population. From an economical view point, there is an obvious solution to this problem: increase the supply of health care. Because health care is composed of both proactive and reactive care, increasing either would be a valid solution. However, increasing the supply of reactive care in the form of rehabilitation and assisted living, for example, would have no positive effect on the demand for health care. Increasing the supply of preventative care (i.e.

improving diagnostics, health education, accessibility, etc.), however, would decrease the demand for reactive care in the long term. Thus, it is clear that focusing on proactive solutions would have a more positive long-term impact on the quality and supply of health care than would focus on reactive solutions.

As mentioned earlier, however, complicated and integrated systems usually cost more than simple robotic systems that perform single tasks. We also need to keep in mind our requirement of delivering both proactive and reactive care to the user. From the previously discussed considerations, the group recognized that a monitoring robot would provide the most benefit to the users, while also being easy to integrate into the current health care system by utilizing existing infrastructure. Our recommendations for a monitoring robot are discussed in the following section.

5.2 Recommendations

Although we consider the need for a proactive solution to be more important, it is important to recognize that the demand for reactive care will never completely disappear. Taking this into consideration, we propose that an ideal personal health care robot should be able to provide both proactive and reactive care. The team has decided conclusively that an **in-home monitoring robot system** would best meet this requirement. Screening individuals for the first signs of disease while simultaneously compiling the data associated with the users would provide a multi-dimensional improvement to the quality of health care. A monitoring system would provide accurate statistics concerning the user's eating, sleeping, and bathroom habits – information that otherwise would be compromised of a guess by the patient during a regular doctor visit. Not only would the information be more accurate, it would also eliminate the need for doctors and nurses to collect such information manually, freeing up a valuable human resource. In addition to tracking the user's habits, special sensors would give doctors access to information they wouldn't have had access to before, namely biological marker levels inside the body. This data can be correlated to the patient's condition, providing a map by which future diagnoses can be made. Above all, a monitoring system would allow the user to live safely and comfortably in their own home, confident that, should anything happen to them, they would be assisted as soon as possible. Several conceptual approaches to designing such a robot are presented in the next sections.

5.2.1 Morphology

We recommend a robot with a functional morphology.

The morphology of a monitoring robot will most likely be functional due to the delocalized architecture. The robot may be given some humanoid characteristics, however, such as a synthetic voice it may use to communicate with the different users. Interacting with the robot through speech may be a more convenient method of interaction for the primary user, and may also make the robot seem more personable.

5.2.2 Autonomy

We recommend a robot with a high ("combination") degree of autonomy.

The autonomy of a monitoring robot is determined by its decision-making capability or lack thereof. The robot must recognize that the user is in danger in some way, either through direct input by the primary user or through recognizing specific sensory cues obtained from the said user. The more cues the robot is able to recognize, the more sophisticated its decision-making capability. Higher decision-making capability implies higher autonomy and therefore less need for human intervention. Less human intervention means that an individual supervisor can be responsible for more monitoring robot systems. The primary user, on the other hand, will only experience improved care from a highly autonomous monitoring robot. A higher level of autonomy should not have a detrimental effect on the acceptance of the robot by its primary users.

5.2.3 Architecture

We recommend a robot with a delocalized architecture.

Existing monitoring systems like eNeighbor generally have a delocalized robot architecture in which the sensors, processors, and actuators are dispersed throughout the robot's work environment. This is typical of tele-presence robots in general. A delocalized architecture is necessary for a monitoring application because different users interact with different components of the system in different locations. The primary user interacts with the system in his/her home. Based on the cues the system receives from this user, it actuates by informing the secondary user, or the supervisor, of the primary user's status. Because the supervisor is located away from the primary user's home, the robot's actuators must be separate from the sensors in order to successfully interact with the supervisor. These individual systems of delocalized sensors, processors, and actuators form a robot team, in which multiple identical systems operate simultaneously to achieve a common goal. The goal of this cooperation is earlier, more accurate diagnoses for the primary users. The sensing, processing, and actuating components are discussed in the following three sections.

Sensing

We recommend a robot with the sensing capacity to observe its user.

There are various forms a monitoring robot can take on. We will break down the possibilities by component, the sensor(s), processor(s), and actuator(s). The main objective of a monitoring robot is to observe the primary user, who will most likely take on the role of peer. The manner in which the robot observes the user is determined by the sensing capabilities of the system. Existing systems, such as HealthSense's eNeighbor, are composed of several simple sensors that recognize when the user uses the toilet, opens the refrigerator, walks into a certain room, is in bed, etc. The user is also able to communicate with the system via a button that alerts medical personnel of an emergency. This requires the user to have access and the capacity to press the button in time of emergency, which obviously is not always possible. The sensing capability of an eNeighbor-style monitoring system is somewhat limited in that it can only provide the information listed previously and that it is not 100% effective in recognizing emergencies. The concept of such a system, however, is an important breakthrough.

Another way to monitor a user's behavior is by means of video and audio. Sophisticated facial recognition and 3D mapping software exists even today. Software that enables a 3D camera to observe a patient and recognize the activities they perform while simultaneously compiling all of this information into a database would provide security for the user because such a system could be able to detect an emergency on its own, in addition to providing a gold mine of data for the medical community. This robotic system would also be particularly useful for patients with a high risk of heart attack or stroke. The system would alert medical personnel as soon as the attack takes place. Audio sensing capability would also allow the user to communicate with the robot verbally. This feature would provide added convenience. Of course, understanding the user's behavior solely will not necessarily provide extremely useful diagnostic information. The observation of the user's biological condition requires the use of biosensors.

Various biosensors have been and are under development. Biosensors are physiochemical sensors that function by converting a chemical stimulus into electricity. As these sensors improve in quality and shrink in size, they will likely begin to find their way into our bodies. NASA has recently developed the Biocapsule, a tiny implant that is capable of diagnosing and treating a disease. The Biocapsule utilizes carbon nano-tubes filled with cells sensitive to a customizable "trigger" and releases specific cells or a secretion as a counter measure. This technology utilizes living organisms as a sensor. Biosensors such as these can be used to detect the first signs of various diseases in patients. The user's condition can be correlated to any biomarkers detected in his/her body, leading to more accurate diagnoses at much earlier stages of disease progression in the future. The application of biosensors into a robotic or smart monitoring system will create a truly proactive solution to the rapidly growing demand for health care. Being able to isolate and treat nearly any disease at an earlier stage greatly increases the likelihood of successful treatment and patient survival.

Processing

We recommend a robot with the processing capacity to recognize emergency situations and the warning signs of diseases.

A combination of video, audio, and biological monitoring can provide security, convenience, and good health to the primary user, while providing valuable data for the secondary user, namely the doctors and nurses, that would greatly improve and also standardize the diagnostic process. This brings us to the next component of our proposed monitoring system – the processor. In order to be a truly valuable robot, it must be able to compile the data it collects into a database. In this database, the robot must correlate the information it collects with the user's known condition. These correlations can then be reapplied to recognize risk factors that may have otherwise gone unnoticed. It is clear that a higher volume of data would result in better correlations and thus diagnoses, but this requires an infrastructure of information systems connecting all medical facilities around the country. The sensors in various homes, hospitals, etc. would upload data to a main database while simultaneously downloading patterns to look out for. The basic infrastructure already exists in the form of the internet and hospitals around the country, like UMASS Memorial in Worcester, MA, for example, have already implemented patient information databases intended to improve diagnoses. These existing databases need to be unified and connected to sensors such as those mentioned previously to create a ceaseless, accurate data collection system. With data being constantly collected and correlated, the robot must be able to actuate when necessary.

Actuating

We recommend a robot with the actuating capacity to communicate information to the secondary users, namely the primary user's relatives, care takers, and health care providers.

The robot system must be able to alert medical personnel in case of an emergency as well as interact with the user to at least some level. For example, the system can synthesize voice in order to communicate with the user, reminding him/her to take medications, ask them how they are feeling, inform them of incoming phone calls or people at the door, etc. More importantly, however, the system must be able to notify the user's family, a doctor, paramedics, etc. in case of emergency. The nurses or technicians supervising the robot can be informed directly and relay the message to the appropriate individual(s). Alternatively, the robot can inform the user of his/her current state and make "healthy" recommendations, etc.

There are numerous ways in which a monitoring robot could interact with users, and this will likely be customizable, should systems like this become popular. The important thing, however, is to establish a unified infrastructure of sensory systems, information systems, and the technicians, doctors, nurses, etc. that will be supervising the patients through the robot. This type of system, regardless of the specific ways in which it would interact with the user, would allow smaller numbers of medical professionals to care for a greater number of patients, thus making quality health care more accessible as well as consistent throughout the country.

6 Conclusion

The monitoring robot system proposed in the previous chapter has the potential to improve both the accessibility and quality of health care, and is also capable of being adapted to new technologies as they are developed. This adaptability helps make the robot an effective long term solution. Telepresence technologies performing both constant monitoring and predictive diagnosis, such as the proposed robot, can help eliminate the need for large hospitals and nursing homes as proper health care becomes more accessible and useful to patients and the elderly in their own homes. However, there are several other quickly growing technologies that could also be applied to home health care, and should be considered before designing a robot for such a market.

6.1 Future Trends of Robotics in Home Health Care

Another large area of interest the team found throughout the study and from the background research was the current trend of robotics in the health care industry. From interviews with industry experts, three areas were identified:

- Rehabilitation Robots
- Telepresence Robots
- Prosthetics

Interestingly, every interviewee mentioned and selected rehabilitation and prosthetics as the most promising areas. Unlike home health care robots, rehabilitation and prosthetics devices/robots do not depend on their cost, but instead on functionality, reliability and the needs of patients: *"Prosthetics are very expensive, but with recent advances, you can get devices that do a great job for the patients." (Thomas Ryden, VGo Communications)*.

In hospital settings, robotics tends to have more resources than in home settings, such as government funding, professional medical devices, or insurance policies. When in hospitals, robots work in simpler, cleaner environments, making them more efficient and less prone to needing repair. Additionally, in this kind of setting robots receive much more frequent professional maintenance, greatly extending their lifespan and efficiency. So we can see that these kinds of robots are not “consumer-facing” robots but can be classified as “high-tech” ones.

Rehabilitation applications of these “high-tech” robots especially seem to have a bright future; according to Dan Kara, there are more than 700 thousand cases of strokes in the United States every year. Based on this huge potential market, administrators, caregivers, and regulatory authorities are all interested in developing and applying new cost-saving technology in the health care industry. They all know that robotic technology would save resources and enable the aid of thousands of patients. The area of prosthetics is actually an expanded branch of rehabilitation.

Prosthetics is very close to “physical rehabilitation” with additional mechanical technology involved. One of the biggest focuses of prosthetics is in military. The U.S. Army has already developed several types of powered exoskeleton suits, many of which are already in action. Government-driven funds will advance the field of prosthetics even more in near future. Since the exoskeleton suits need more improvements and innovations, there is nearly unlimited potential in the market of prosthetics.

6.2 Impact

Although future directions for the proposed monitoring robot could include these other kinds of rapidly growing technologies, the monitoring-only version recommended here has the potential to accomplish the objectives we set forth in the beginning of the report. The proposed robot:

- Allows the elderly user to age in place;
- Assumes some of the responsibilities of various health care personnel, freeing up human resources;
- Improves timing and accuracy of diagnoses;
- Makes health care more accessible to people that need it.

The robot also meets the various user requirements we identified in our research and studies, such as the need to be easy to use, affordable, and provide a sense of security for the user. The delocalized structure also makes it easily integrated with other technologies, and leaves the possibility for future improvements and additions, possibly in the rapidly advancing fields discussed earlier in this chapter. Integrating all monitoring robots into a single system is important because that aspect provides the proactive functionality of higher quality diagnoses. By following these recommendations, a monitoring robot would provide not only an immediate, reactive response to health care shortages, but also a long-term, proactive solution to the issues that face both the elderly and the current health care industry.

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Appendix A: IRB Approval

100 Institute Road
Worcester, MA 01609-2280, USA
508-831-5000, Fax: 508-831-6090
www.wpi.edu

Worcester Polytechnic Institute IRB #1
IRB 00007374

31 October 2011
File: 11-152

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609

Re: IRB Expedited Review Approval: #11-152 "The Emerging Role of Robotics in Smart Health care"

Dear Prof. Tulu,

The WPI Institutional Review Committee (IRB) approves the above-referenced research activity, having conducted an expedited review according to the Code of Federal Regulations 46.

Consistent with CFR 46.116 regarding the general requirements for informed consent, we remind you to only use the **attached stamped approved consent form** and to give a copy of the signed consent form to your subjects. You are also required to store the signed consent forms in a secure location and retain them for a period of at least three years following the conclusion of your study. You may also convert the completed consent forms into electronic documents (.pdf format) and forward them to the IRB Secretary for electronic storage.

The period covered by this approval is 31 October 2011 until 30 October 2012, unless terminated sooner (in writing) by yourself or the WPI IRB. Amendments or changes to the research that might alter this specific approval must be submitted to the WPI IRB for review and may require a full IRB application in order for the research to continue.

Please contact the undersigned if you have any questions about the terms of this approval.

Sincerely,

Kent Rissmiller

Kent Rissmiller
WPI IRB Chair

Informed Consent Agreement for Participation in a Research Study

Investigator: Bzura, Conrad Im, Hosung Liu, Wan Malehorn, Kevin

Contact Information:
conradbzura@wpi.edu hosungim@wpi.edu tammy_liu@wpi.edu kmalehorn@wpi.edu

Title of Research Study:
Emerging Role of Robotics in Smart Health Care

Introduction
You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study:
Our goal is to investigate the current state of robotics technologies in smart health care, identify which areas of robotics are quickly growing, and determine which kinds of robotics technologies can be used to have a positive impact on the health care industry.

Procedures to be followed:
In order to achieve the above objectives, we need information from the attendees of the conference professionals concerning current trends of robotics technologies. If you volunteer to participate in this study, you will be asked a few open-ended questions. These questions will ask about your opinions and predictions concerning the future of robotics technologies, as well as current trends in the industry, especially in relation to smart health care. As space allows, we will conduct interviews with a voice-recording audio device either standing in a public place or sitting in private rooms.

Risks to study participants:
No risk.

Benefits to research participants and others:
If the subject agrees to have their identity available, they may receive recognition upon publication of the project. Additionally, the research should help the project team with their final goal of developing a set of user requirements for a health care robot, which may guide future home health care robot design.

Record keeping and confidentiality:
The interviews will be secured by our IQP team until our return to campus, at which point we will convert the interviews to text and destroy the audio recordings. Converted text data will be kept in WPI's secure servers for 3 years and then will be destroyed. The information gathered, including any identifying information, will remain confidential until it is incorporated into the report (identifying information will ONLY be disclosed with the consent of the interviewee, otherwise it will remain confidential). Please note that there will be check boxes on the last page asking you to allow us to quote information with your identifying information.

Compensation or treatment in the event of injury: There will not be any risk of injury or harm involved. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:
Contact information of investigators provided at top of page.
IRB Chair : Professor Kent Rissmiller,
Tel. 508-831-5019, Email: kjr@wpi.edu
University Compliance Officer : Michael J. Curley,
Tel. 508-831-6919, Email: mjcurley@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may stop participating in the middle of interview at any time by any reason. Data obtained in this interview will become the property of the investigators and WPI. If you withdraw from the study, data already collected from you will remain in the study as anonymous.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing.

☐ You prefer to remain anonymous. No indentifying information will be published.

☐ You allow us to use your answers under your name on our final project.

____________________________ Date: ____________________
Study Participant Signature

____
Study Participant Name (Please print)

______________________________________ Date: ____________________
Signature of Person who explained this study

Approved by WPI IRB
From: 10/31/2011
To: 10/30/2012

Focus Group Approval (IRB Exemption Approval)

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Worcester, MA 01609-2280, USA
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Worcester Polytechnic Institute IRB #1
IRB 00007374

28 November 2011
File:11-152

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609

Re: IRB Application for Exemption #11-152 "The Emerging Role of Robotics in Smart Health Care"

Dear Prof. Tulu,

The WPI Institutional Review Committee (IRB) has reviewed the materials submitted in regards to the above mentioned study and has determined that this research is exempt from further IRB review and supervision under 45 CFR 46.101(b)(2): "Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation."

This exemption covers any research and data collected under your protocol from 28 November 2011 to 27 November 2012, unless terminated sooner (in writing) by yourself or the WPI IRB. Amendments or changes to the research that might alter this specific exemption must be submitted to the WPI IRB for review and may require a full IRB application in order for the research to continue.

Please contact the undersigned if you have any questions about the terms of this exemption.

Thank you for your cooperation with the WPI IRB.

Sincerely,

Kent Rissmiller

Kent Rissmiller
WPI IRB Chair

Appendix B: Project Plan

	Task Name	Duratio	Start	Finish	Resource Names	Ad
1	Register for project	1 day	Wed 4/6/11	Wed 4/6/11	All	
2	Refwork account, mailing list, sharepoint requested	6 days	Wed 4/13/11	Wed 4/20/11	All	
3	Readings assigned for the summer	83 days	Tue 5/10/11	Thu 9/1/11	All	
4	**2011 A term Literature Review**	36 days	Thu 8/25/11	Thu 10/13/11		
5	**Draft proposal 1**	**32 days**	**Wed 8/31/11**	**Thu 10/13/11**	**All**	
6	**Format**	**10 days**	**Fri 9/23/11**	**Thu 10/6/11**	**All**	
7	Table of Contents				Kevin	
8	Cover page and page number	2 days	Fri 9/23/11	Mon 9/26/11	Kevin	
9	IEEE citation (not bibliography)	4 days	Fri 9/23/11	Wed 9/28/11	All	
10	Visual element, incorporate picture with captions	2 days	Fri 9/23/11	Mon 9/26/11	All	
11	**Problem Introduction (2-3 pp)**	**11 days**	**Wed 9/14/11**	**Wed 9/28/11**		
12	Motivation (1-1.5 pp)				Kevin	
13	Problem statement in bullet list				Conrad	
14	Layout paragraph				Tammy	
15	**Background (literature reviewa)**	**24 days**	**Wed 9/14/11**	**Mon 10/17/11**	**All**	
16	Taxonomy	14 days	Wed 9/28/11	Mon 10/17/11	Conrad	
17	Demographic	14 days	Wed 9/14/11	Mon 10/3/11	Kevin	
18	Market	14 days	Wed 9/14/11	Mon 10/3/11	Tammy	
19	Current Technologies	14 days	Wed 9/14/11	Mon 10/3/11	Hosung	
20	**Methodology**	**40 days**	**Sun 10/23/11**	**Thu 12/15/11**		
21	Summit ElderCare Email and methodology	15 days	Thu 11/10/11	Wed 11/30/11	Tammy,Conrad,Kevin	
22	WPI Focus Group Methodology	13 days	Thu 11/10/11	Mon 11/28/11	Kevin	
23	Focus Group IRB doc modification	10 days	Fri 11/11/11	Thu 11/24/11	All	
24	**RoboBusiness Data methodology**	**7 days**	**Sun 10/23/11**	**Mon 10/31/11**	**Kevin,Tammy,Hosung**	
25	RoboBusiness consent form	1 day	Thu 10/27/11	Thu 10/27/11		
26	IRB submission	9 days	Tue 10/18/11	Fri 10/28/11		
27	preparation for interviews	2 days	Fri 10/28/11	Mon 10/31/11	All	
28						
29	**2011 B term data collection and analysis**	**15 days**	**Wed 11/23/11**	**Tue 12/13/11**		
30	**RoboBusiness Interview**	**2 days**	**Wed 11/2/11**	**Thu 11/3/11**	**Kevin,Hosung,Tammy**	
31	Follow up RoboBusiness interviews	29 days	Thu 11/3/11	Tue 12/13/11	All	
32	**Focus Group**	**10 days**	**Wed 11/23/11**	**Tue 12/6/11**	**Prof. Tulu**	
33	Campus recruitment for WPI FG	1 day	Tue 11/29/11	Tue 11/29/11	All	
34	Focus Group Poster design	5 days	Wed 11/23/11	Tue 11/29/11	Hosung,Tammy,Kevin	
35	Summit ElderCare Invite to Dr. Wildner	1 day	Wed 11/30/11	Wed 11/30/11	Tammy	
36	FG 1 (recruited with our friends)	1 day	Wed 11/30/11	Wed 11/30/11	Hosung Tammy	
37	FG1 PPT	3 days	Mon 11/28/11	Wed 11/30/11	All	
38	1st round FG follow-up and transcription	2 days	Wed 11/30/11	Thu 12/1/11		
39	Continued interview with 3 prof 1 student	9 days	Wed 11/30/11	Sun 12/11/11		
40	Focus Group Protocol restructure	5 days	Wed 11/30/11	Tue 12/6/11		
41	**FG2**	**13 days**	**Wed 11/30/11**	**Fri 12/16/11**		
42	ppt revision	4 days	Wed 11/30/11	Mon 12/5/11	All	
43	FG2 transcription	3 days	Mon 12/5/11	Wed 12/7/11	Kevin	
44	Focus Group Books reading	3 days	Mon 12/5/11	Wed 12/7/11	Tammy	
45	Confirm data for focus group 1	3 days	Wed 12/14/11	Fri 12/16/11		
46	Confirm data for focus group 2	3 days	Wed 12/14/11	Fri 12/16/11		
47	Qualitative data analysis	5 days	Mon 12/5/11	Fri 12/9/11	Hosung,Conrad	
48	**Further contact with Summit**	**5 days**	**Tue 12/6/11**	**Sat 12/10/11**	**Annamaria Salisbury**	
49	Transcribe ElderSummit Care	3 days	Tue 12/13/11	Thu 12/15/11	Kevin	
50	Confirm audio data for individual interview	3 days	Wed 12/14/11	Fri 12/16/11	Kevin	
51	Manage all interview list in B term	2 days	Fri 12/16/11	Sun 12/18/11	Kevin,Tammy	
52	Confirm audio data for RoboBusiness	5 days	Mon 12/19/11	Fri 12/23/11	Hosung	
53	Contact the club	1 day	Wed 12/14/11	Wed 12/14/11	Tammy	
54	Schedule C term meeting time		Wed 12/14/11		Tammy	
55	Taxonomy conclusion				Conrad	
56						

	Task Name	Duration	Start	Finish	Resource Names	Ad
57	**2012 C term**	**37 days**	**Thu 1/12/12**	**Fri 3/2/12**		
58	**B term data analysis continue**	**6 days**	**Thu 1/12/12**	**Thu 1/19/12**		
59	Chapter 3 Methodology section write-up	8 days	Thu 1/12/12	Mon 1/23/12	Conrad,Kevin	
60	Data comparison methodology (changes between protocol)	2 days	Thu 1/12/12	Fri 1/13/12	Kevin	
61	Adding Participant background info to methodology	1 day	Thu 1/12/12	Thu 1/12/12	Tammy,Kevin	
62	FG Transcritions		Mon 1/23/12		Kevin	
63	**Result section coding**	**21 days**	**Thu 1/12/12**	**Thu 2/9/12**	**All**	
64	Coding doc write-up	5 days	Mon 1/23/12	Fri 1/27/12	Kevin,Conrad	
65	RoboBusiness Coding	14 days	Fri 1/13/12	Wed 2/1/12	Hosung	
66	Summit Coding	14 days	Fri 1/13/12	Wed 2/1/12	Tammy	
67	2 WPI FG Coding	13 days	Fri 1/13/12	Tue 1/31/12	Kevin	
68	**First final report revision**	**23 days**	**Sat 1/7/12**	**Tue 2/7/12**	**All**	
69	Formatting, citations, graphs	5 days	Sun 1/29/12	Thu 2/2/12	All	
70	Combine Taxonomy with report	11 days	Tue 1/24/12	Tue 2/7/12	Conrad	
71	Updated information from industry/ robot	1 day	Sat 1/7/12	Sat 1/7/12	Kevin	
72	Final revisions to report (formatting, citations, etc.)	8 days	Mon 2/20/12	Wed 2/29/12	Kevin,Tammy	
73	**Second final report revision in C term**	**14 days**	**Wed 2/8/12**	**Mon 2/27/12**	**All**	
74	**Corrections to Ch 5 based on comments**	**6 days**	**Mon 2/20/12**	**Mon 2/27/12**	**Conrad,Kevin**	
75	Abstract and executive summary	2 days	Mon 2/27/12	Tue 2/28/12	Conrad	
76	Complete appendices and attach to file	6 days	Mon 2/20/12	Mon 2/27/12	All	
77	**Presentation preparation**	**5 days**	**Mon 2/20/12**	**Fri 2/24/12**	**All**	
78	**Taxonomy section**	**31 days**	**Fri 1/13/12**	**Fri 2/24/12**	**Conrad**	
79	Poster	3 days	Thu 3/1/12	Sat 3/3/12	Conrad,Tammy	
80	Project plan	138 days	Thu 8/25/11	Mon 3/5/12	Tammy	
81	**Final Report Revision**	**5 days**	**Mon 2/27/12**	**Fri 3/2/12**	**All**	

Appendix C: Notes from Studies

RoboBusiness Interviews

Please note: The following interview responses are not all direct quotes, but contain many of the interviewee's words. Some changes were made for brevity, readability, or to improve later analysis.

Interviews with Angle, Kara, and Ryden were conducted Nov 2 by Kevin Malehorn and Hosung Im. Interviews with Clothier, Larson, McGrath, and Rapacki were conducted Nov 3 by Tammy Liu. All interviews were conducted at the RoboBusiness Leadership Summit 2011 in Boston MA. WPI IRB approval for these interviews can be found in Appendix A.

COLIN ANGLE

Interviewer: (#1) Please introduce yourself. How familiar are you or your company with the application of robotics in health care?

Angle: CEO, co-founder, chairman of the board of iRobot corp, in industry & CEO of iRobot for 21 years.

Long been a passion, a field of robotics still in very earliest stages, one of most successful companies out there that has over 400 robots deployed in hospitals called inTouch Health - allow specialists (doctors) not present at that hospital to communicate with patients that need diagnosis; that's what we're doing today, and that just ultimately scratches the surface of what we will need from robots in health care.

I: Mentioned earlier in talk home care for elderly, what direction is that going, and is iRobot involved in that?

A: They are certainly interested. The challenge with **home** health care is first what you need to do is fairly hard, you need to actually help meet the physical needs of an aging parent or loved one, and you need to do it at a price that can be afforded; if you're only creating solutions that help the wealthy, the wealthy have other options (hire people to come & meet their needs); you need to do this all at a very aggressive and low cost. We're talking about a problem that is going to grow over the next 20 years, and we're also talking about a problem that is going to take the next 20 years to solve in a real way.

And there's lots of steps along the way, lots of things we can do; today - end of the road for living independently is when they don't answer the phone frequently [mom across street with friends, doesn't answer], near-term application; also near-term is robots used to more proactively ensure compliance to a medicinal regime, which can become incredibly complicated, remembering not always the problem, getting up & getting to meds often can be the problem, or simple denial (remind *why* you need to be taking these meds).

I: So it's not just physical robots, but it could be integrated with health care systems & notifying doctors "like" remote information.
A: I agree, robot could be service end of a significant network of information & people/caregivers that combine to give the person the independence they need to stay where they want to be.

I: Which sounds related to iRobot's biggest product, Roomba

A: Roomba certainly part of a solution, because living independently is not just caring for you, it's caring for the home; one of most vocal & appreciative demographics with Roomba is "the cleaning-challenged" have difficulty pushing vacuum (age or other), "over the moon" with thanks & appreciation that Roomba can do that for them, so they can feel more "house proud", better about environments they're living in, and not dependent on someone coming once a week, visitors to clean home more frequently.

I: (#4) Earlier you were citing cost a barrier, do you think that's the main thing holding robots back from becoming part of our lives, like a lot of other technology already is? or maybe it's something else, like a lack of understanding?

A: Cost is one of the important factors, understanding what a robot can do to truly make our lives easier is another factor, and delivering on the promise once you've figured out what you want the robot to do is another factor; think of videogame industry: pong incredibly simple, 2 bars, 1 ball; now videogames 10 million times more complex (or more), yet pong was still fun.

Challenge with robot industry is what we're trying to do (ex: first vacuuming robot can only clean 1/500 cheerios, wouldn't sell) expectation is that Roomba will clean floor as well as human can clean floor; so bar to minimum acceptability to a robot solution is set on par with a human, and that's a very difficult standard to meet. "Anyone who thinks the robot industry is easy, and they can come in and do something simple badly and work their way up often finds that robotics is a little unforgiving in that regard." But we certainly are moving in a good direction, and there are many robots that meet that hurdle, that are good exemplars.

I: (#2) I know you may not be too involved with healthcare robotics, but we were wondering if you had some insight into which areas of that were developing quickly and looked like they were promising areas on the horizon, kind of like the patient monitoring you were talking about or rehabilitation or things like that.

A: Number of very exciting companies in rehabilitation regime, and prosthetic regime: iWalk (new local company, founded by Hugh Herr) to make robotic ankles, DEKA - amazing robot arms "making a difference out there."

Then there's a number of interesting companies that use robotic technology to help stroke victims to recover motion & be able to walk in more natural gait; those are areas where we're starting to see real solid business model robot companies come into existence to help with tangible, debilitating injury, and that's great. So that's an area where you've got concrete need and an appropriately-costed solution coming together to create businesses, that's a growing area.

And using remote presence to leverage doctors is an area where we're seeing a significantly growing opportunity for business, and I mentioned inTouch health as one player in that domain that is seeing such success.

The home area is a little more nascent at this time, simply because of the cost associated with robots in the home, and it's going to have to develop as the technology gets more proven and companies can invest getting the cost out of these systems and mass-manufacturing techniques to make these technologies affordable. So I see that happening delayed from some of these more high value and institution-based solutions.

Quotes from Colin Angle

“The challenge with home health care is first, what you need to do is fairly hard. You need to actually help meet the physical needs of in aging parent or loved one, and you need to do it at a price that can be afforded. If you are only creating solutions that help the wealthy, they have other options; they can hire people to come in and meet the need. You need to do this all at a very aggressive and low cost. So we are talking about a problem that is going to grow over the next 20 years, and we also are talking about a problem that is going to take the next 20 years to solve in a real way. There are lots of steps along the way.”

"Prosthetics, rehab, both are very quickly developing fields and most promising area. For prosthetics there are several very good companies like iWalk and DEKA. Rehab is rapidly growing to help stroke victims to recover. Home health care is more 'nascent' at this time because we still have the cost issue with robots at home. It will grow as technology becomes more proven and companies invest. Getting cost out of systems and mass-manufacturing techniques we can make these technologies affordable. It was delayed from more high values and institution-based solutions."

"Anyone who thinks the robot industry is easy, and they can come in and do something simple badly and work their way up often finds that robotics is a little unforgiving in that regard"

“IRobot is focusing on helping elderly to live 'independently', Roomba aids in that manner. One of the most vocal and appreciative demographics of Roomba is the 'cleaning-challenged' like elderly or disabled people and we want them to be 'house proud' with increased independence.”

"it is going to have to develop as the technology gets more proven and companies can invest in getting the cost out of the systems and mass-manufacturing techniques to make these technologies affordable. So I see that happening delayed from some of more high-value and institution based solutions"

"I think the cost is the one of the important factors, understanding what a robot can truly do to make our lives easier is another factor, and delivering on the promise once you figure out what you want the robot to do is another factor because in some industries you create something..think of video industry, the first video game 'pong' was one dot slowly moving the screen and bouncing off a bar. you compare that video game today is 10M times more completed in all of this sophistication and yet 'pong' is still fun. The challenge with the robot industry is what we do (taking vaccuming for example). if the first Roomba cleaned up one cheerio in my kitchen but left 500 other cheerios scattered around, i would hardly believe it would sell very many and i do not believe anyone would be particularly excited to own Roomba because our expectation, is that Roomba will clean the floor as well as human can clean the floor. So that the bar to a minimum acceptability or a robot solution is set on par with a human and that is a very very difficult standard to meet. "

DAN KARA

Interviewer: (#1) Please introduce yourself. How familiar are you or your company with the application of robotics in health care?

Kara: President Electra Studios, past-President & founder Robotics Trends, founder and chairman of RoboBusiness.

I am very familiar with that and I do know of *some* applications of home health care for elderly, but most of those are research projects as opposed to commercialized products.

I: (#3) Where do you think robotics could help benefit health care the most? What's developing quickly or what's popular?

K: The ones you listed are ones that are growing quickest, discussed these things in his presentation (highlighted in red), hospital automation eliminated; the largest is robotic surgery; fastest growing rehab, prosthetics, or telepresence surgery; prosthetics - "accidents & people coming back for more", much smaller marketplace because people are surviving longer.
Interesting, possibly quickest-growing is rehab market - driven by one thing only: *stroke*; massive marketplace even so, as baby boomers grow older, demographic of those vulnerable to stroke increases, particularly as people are overweight or don't exercise as much; something you can robotitize: "with neuroplasticity & things", if you exercise that appendage, you cannot regenerate but 'awaken' dormant neurons to find other pathways, so works with injury, but primarily driven by stroke, and it's massive number if you look it up, Americans per year, I think on the order of 700 thousand people per year, and large percentage survive [~600k according to a site I just checked -Kevin].
So this marketplace to provide continuous monitoring over time is a growing market. Robotics interventional systems is growing as well, particularly with things such as knee surgery, but now they're moving into knee replacement, hip replacement, driven by demographics and moving into prostate surgery, brain surgery, so also growing quickly. But probably rehab would be my guess as the largest.

I: Treatment for stroke or rehab, is that used in the home settings?

K: Absolutely in home settings. cost is primary driver, and amount of time it takes to care for elderly (as Colin Angle alluded to), better just to have device there being rented typically by insurance company. Number of robot devices out there made just to exercise a part of the body - real sensors in there, determine pressure, act accordingly, take info and send to the health care provider at the rehab center or hospital. They are using it at home, that's something you can't do with surgery.

I: (#4) Technology a large part of our lives, why is robotics not? What are the barriers? Cost?

K: We actually did quantitative research on consumer robotics to see what the problem was, and a lot of it was driven by cost; other things: people unsure whether it would work [deliver functionality]. What we found was interesting: "it doesn't have to work as good, it just has to work as advertised." Roomba not as good as me, but it means I don't have to vacuum every day. Also, there *are* a lot of robots in people's lives, but they don't realize they're robots. I talked earlier about self-driving cars; energy-efficient smart washing machines - have sensors in them - **notion of *sensing, thinking, and acting*, that's a robot**. Sense what's going on, whether wash needs something or if stuff is still dirty, adjust cycle time to accommodate or weight of clothes in there, overriding original human adjustments. So I think in many cases people don't actually understand what a robot is, and how ubiquitous it is.

I: So it's not necessarily just a single robot. It could be like ones that communicate with medical personnel and just monitor patients, something like that.

K: Yes, absolutely. Again, sense, think & act.

I: (#5) Any final comments about robotics or health care?

K: Again, being driven mostly by demography and cost. Even with interventional (surgical) systems, they can get people out of the hospital surgery with "that type" of surgery (forgot name [arthro/laparoscopic?]) as opposed to opening up patient - can just get them out quicker; incision size smaller, recuperation time smaller, some advances in efficacy. But rehab is being driven by demography (typ. stroke tied to population) and surgery is being driven just by cost.

I: So it's more cost-efficient for them to use?

K: More cost-efficient, in many cases it'll do a better job, like grinding out bones, replacing hips, robots do better job than even most skilled surgeon. So there is some efficiency and efficacy, but again, it's cost - they want to get those beds opened up to bring more people in.

Quote from Dan Kara

"It doesn't have to work as good; it just has to work as advertised. Roomba is not as good as a human, but you don't have to vacuum every day." (Dan Kara, Electra Studios)

THOMAS RYDEN

Interviewer: (#1) Please introduce yourself.

Ryden: COO & co-founder of VGo Communications (make telepresence robot used in number of markets including health care) for 4 years, prior to that was with iRobot about 7 years, in field about 11 years doing robotics.

I: Your telepresence robot, is that used mostly in hospital settings?
R: So it's used in a couple of different settings, there are the applications really dependent of hospitals [and other areas?] & services they are performing. So example applications: patient visit - robot in hospital, usually in common area, hospital allows people to call in to robot & drive around & talk to patients while they're in the recovery area; gives opportunity to people who are distant from hospital, instead of going to visit, they can call in.

Other app: remote training, doctor who can't visit for surgery will call in on robot & tour & visit & participate in that surgery remotely; extension of doctor or nurse - e.g. rural clinics, don't have the doctors in a central hospital, can't make it to rural clinic, will call out to rural clinic's robot in that location & then talk to patients & so forth through robot.

I: Ever used in home applications?

R: Yes, we do have some home applications. Health care - send robot home with patients after surgery, remote doctor to check up on recovery.

I: While at home rehabilitating?

R: Exactly, usually for a couple of weeks after surgery, that's application they use it for. Other one similar is elder care; idea here is we have number of telepresence robots in homes of elderly where sibling or child can call in to see how grandma's doing or whatever and it keeps them company (companion) but also remote device that somebody else can drive around.

I: (#3) Any insight into what kinds of robotics technologies are developing quickly? We cited prosthetics, telepresence, surgery robots.

R: You mentioned the big ones. I think rehab robots is growing incredibly quickly, in my mind that's anything that's a "robot-assisted type of device", e.g. robots you can put on your leg or arm that help you recover from ***<u>stroke</u>***, and helps you regain motion you might have lost.

And then prosthetics themselves: iWalk - robotic ankle, another company that's developing a robotic arm, and there's full exoskeletons that allow you to "replace" damaged areas of your body and also assist & allow soldiers to carry more, so that's an area that's growing rapidly both in technology that's being deployed, as well as the applications.

You mentioned robotic surgery, don't know a lot about, but you see success of da Vinci & others. Rehab & prosthetics two biggest areas - what's contributed to those is reduction of cost of some of the components. A lot of robotics is leveraging off [advancements in] other fields (like power - small batteries, low power consumption), before robots or prosthetics were very limited (1 hour robotic ankle not very useful), but now with increase in battery-/power consumption-related tech that's not going to happen, you can use it all day.

I: So as the cost becomes lower it becomes more feasible to implement them

R: Yeah, health care's not driven as much by cost (although you see that), but more by application & capability.

I: So it's driven by what the patient's need is basically?

R: Right, exactly. So prosthetics are very expensive, "they can absorb some of the technology, but can it actually do the job?" With more efficient motors, power distribution & all that you can actually get these devices that really do a great job for the patients.

I: Technology in our personal lives, but robots not as commonplace. What do you think about that? Maybe that's an actual cost issue rather than a need thing?

R: Yeah, in the home there's 2 things, it is much more cost. It's much more cost-driven. Colin Angle's talk - electrolux robotic vacuum ~$2k not successful, but Roomba was at a few hundred; there are price points that consumers just won't pay, so you're going to have to get down low enough to have these robots be widely accepted.

And the other thing is sensor capability - the ability to actually operate in a home environment is a little bit different, and people expect it to work all the time. Environment very different from home to home, need it to work pretty much all the time.

I: And there's not a lot of maintenance.

R: Exactly, very limited maintenance, has to charge itself; rugs with tassels, dogs or cats or whatever, it has to work in that environment. And that's very different than a hospital, where all floors polished, nice, clean, not many obstacles, very different operating environment. I think until vacuums and floor scrubbers, etc., as they become more advanced in capability to move through that cluttered environment, I think you'll see a lot more robots in the home.

I: VGo - does it fit with your company's goal, or do you think there's more possible improvements in the future for VGo?

R: It's accomplished what we want it to do, in allowing people to be in two places, to remote locations, and to avoid traveling, or allow children to go to school when they couldn't, but I think there's a lot of new applications that will evolve as we can add sensors and capability, and we're continuing to work on that. I think you'll see in the future different accessories added to the product - remote diagnostics, or other certain things to change the environment in the far end. Right now it's just two-way audio/video; a lot of people will want manipulation at the far end.

I: Kind of to separate it from a computer or something like that.

R: Exactly. So it would be able to manipulate (I don't mean arms & whole bit, but maybe move things or dispense things like that at the far end), and I think you'll see that evolve over time.

Quotes from Thomas Ryden

"Full exoskeletons allow 'replacement' of damaged areas of the body and can assist soldiers."

"Home health care isn't driven as much by cost, but more by [the robot's] applications and capability. […] Prosthetics are very expensive but with recent advances, you can get devices that do a great job for the patients."

COREY CLOTHIER

Interviewer: (#1) Could you please describe to us what your current position is and how long you have been in the robotics field?

Clothier: Sure. I am a business analyst for the US Army and I've been doing it for three years. My focus is business strategist for robotics research & development.

I: How familiar are you with robotics applications in healthcare industry?

C: I am pretty familiar. I haven't built or implemented anything but I am very familiar with robotics and I am pretty familiar with assistant living in nursing home.

I: So do you know anything about home care to assist elder independence?

C: Yes.

I: Can you introduce more about what did you do with application in nursing home?

C: With nursing home, I started the facility. We were using not a robotic technology but more like a vision technology with integrated software that could alert a system with melodies*** and could also allow the caregivers to look at any of the non-private resident areas when necessary, just to monitor their safety and health. And also, we have implemented two alarms systems to entrances / exits to doors. Didn't want them to go to outside without supervision. Robotic would be the next logical step to provide companionship, potentially deliver things like food etc. I am not sure about medication. I would think that a caregiver would administer that. But they (robots) could deliver magazines. Companionship would be good, surveillance would be outstanding. Such things, I think it is really useful for elderly care.

I: So are you basically working to sell robots to nursing homes?

C: No, I am not; my business right now is completely different. Basically I am working for transportation's solution for military. But I am actually thinking about it; because I am here this week, I am seriously thinking about getting into health care for the elderly.

I: Are you familiar with the cost and expense of robotic in nursing homes and what are the attitudes from the nursing home to robotics?

C: There are a few attitudes that we need to be aware of the nursing homes. Let's take a look at all of the participants and the stakeholders.

The customer could be the first point of contactor. The ultimate customer would be the elderly person. This is a complete new/ very new technology that they are not used to. But I think they have been perceptive. The people that I've met and discussed these things with have been receptive, and they think it is interesting. In a case, where I've intrigued with, is the popularity of the Wii, the video games in nursing homes and elderly care homes. They love playing Wii, so they really like technology. They think that, you know, humanoid robots, something with personality, I believe they would think that kind of adorable and fun companion. That is one.

<Perceptive, like technology, find humanoid robots adorable>

The caregivers, the nurses and the staff, same thing. They are not really high-tech people, but I think they would be receptive too if this would reduce their workload or make them more efficient.

<Not high tech people, but receptive if reduce workload and help improve efficiency>

Another one is the administrators would be very interested because this would be a cost saving and they could provide a better care, that's why I've been using technology in my facility because I could provide actually a safer and better care for a lower cost.

<Cost saving with better quality of care>

The family members of the elderly would view it as an opportunity and a commitment of the facility. They are actually progressive and they are trying to provide the best care possible.

<Progressive, view as an opportunity>

And the last one that's a really interesting one and I've had lots of lots of conversation with is the regulatory authorities. The health administration would like to license the home. This is completely new. We had long discussed about being able to substitute technology for people. There are no regulations in the US yet, not in the States, at least when I started my assist living facility. So it was a point of attention but they were open to it. They even gave us a short-term waiver and they let us to run a pilot program. So they are open to the idea but they weren't completely sold on it yet.

<Open, no regulations yet for assist living facility, give waiver to run a pilot program>

I: Talk about affordability.

C: Provide affordable robotic to home elder assistance to substitute nurses.

So our system assistant facility in nursing home, our **average cost was about $6,000 per month**. That's a lot. So if you could provide a robot for maybe **less than $1,000 a month** that could provide companionship, monitoring, emergency system, things like that that might be, I think there's definitely a market.

I: Right now, since the cost is high, what kind of customer do you think will be willing to buy this?

C: I believe they would have to be a customer with money. But you know, there may be a leasing model. Think about a leasing model. With a leasing model where a customer doesn't need to spend

$10,000 for a robot but they can spend a certain amount per month for the service. So that's something I've been looking to for a couple of different applications or surveys for leasing arrangements.

<leasing model for service instead of buying a robot>

I: (#2) There are numerous applications for robotics in health care. Which current applications do you see as being the most effective (in terms of cost, functionality, and profit/value)?

C: For healthcare, there are these questions logistically. For assist living in healthcare, delivering food/ services, very simple applications would be really useful. What we mentioned was simple companionship and monitoring, you can do those at a pretty low cost. You don't need a fancy robot for that; there are actually a lot of robots out there in hundreds of dollars or thousands of dollars. And I think those are the best robots for now. Add more technology for less cost, there could be more interaction. More people could log on. We had an interesting system in our video system that we could have a kind of like a skype, video chat, I can log on like a monitor to check to see what my grandmother's doing. But our telepresence was static, you know. With a telepresence robot, they can provide good monitoring and companionship. Also like a medical service, a doctor and nurse at the end of the system to take a look at the patient.

<companionship, monitoring, surveillance, delivery of food/magazine are the things most mentioned for elder assistant living. A robot with low cost with the above functions would be the best solution.>

I: (#3) Specifically which area of health care robotics do you feel is developing most rapidly (telepresent surgery, prosthetics, patient monitoring, rehabilitation, elder care)?

C: I think it's just the telepresence from diagnostic to surgery would be the most rapid. I think we would see more and more on the logistic side. I think the entire industry is moving forward progressively.

< Telepresence from diagnostic to surgery would be the most rapid >

I: (#4) The average person is nearly constantly exposed to technology. What is holding robotics back from becoming part of our daily lives as, for example, smart phones have become? Cost? Scarcity of materials? Lack of demand?

C: Cost can be an issue. The US adults haven't grown mature for robotics. We had a culture that thinks of robot as evil or more in Asia thinking of robots as friendly and helpers, sometimes as heroes. So we have to change, some time a shift. It will take a little bit of time in the US, from media, movies, the terminators that have infiltrated the adults that people with my age, everyone says we will wonder that if the robots will take over. There's that cultural issue that need to change over time. Next generation will be able to do that. That's controlling some of the demand. We also said that cost is the key, and the cost is coming down.

<cultural issue>

Quotes from Corey Clothier

"Administrators would be very interested because this would be a cost saver, and they could provide better care. That's why I've been using [this] technology in my facility because I could actually provide safer and better care for a lower cost."

"What I'm intrigued with is the popularity of the Wii, the video games in nursing homes and elderly care homes. They love playing Wii, so they really like [that] technology."

"[…] humanoid robots, something with personality; I believe they would think [of those as] that kind of adorable and fun companion."

"The US adults haven't grown mature for robotics. We had a culture that thinks of robots as evil, [while people] in Asia think of robots as friendly and helpers, sometimes as heroes. So we have to change, sometime there will be a shift. It will take a little bit of time in the US, from media, movies, the terminators that have infiltrated the adults that people with my age; everyone says we will wonder that if the robots will take over. There's that cultural issue that need to change over time. Next generation will be able to do that. That's controlling some of the demand."

TED LARSON

Please note: Simplified transcription; only key facts and quotes are presented.

OLogic's Products:

- dancing, music-playing robot
    - $300-$400
    - controlled w/ smartphone app
- mechatronic smartphone dock
    - 1st version - $99; 2nd version - $50
    - free open-source app

"We are big believers in the hugest way that in the future of consumer robotics there will be a smartphone in the loop." – due to the immense computing capability of smartphones, tablets, and other devices – "The way to get a lot of the cost out of [consumer robots] is to offload all of the processing to phones, tablets, and devices you already own."

"Everyone wants their robot to be cheap. […] If you look at the market research for consumer robotics, it says that the average price a typical person is willing to pay for a robot is $300. […] It doesn't matter if it's ASIMO, people aren't going to pay more than $300 for it." – a consumer robot must deliver a lot of value, do something really compelling.

The mechanical aspect of robotics is more difficult to accommodate than the software programming and electrical aspects.

“Most [people in robotics] spend more time engineering to solve the problem with whatever technology is available, regardless of cost.” Companies should “value engineer” (focus on engineering *cost-solutions*) their product until it can make it to market and meet the target price – if the target price cannot be met, the product should not be made. Robotic products making it to the consumer market at an affordable price are a rarity.

◊ ROS – Robot Operating System by Willow Garage (software)

PAUL MCGRATH

Interviewer: (#1) Please introduce yourself.

McGrath: Regional sales manager for Maxon Precision Motors, been with Maxon for ~18.5 years (started with Maxon right out of WPI). Engineering support/design engineering with customers & sales perspective; on management side: oversee 3 other sales engineers encompassing whole east coast.

I: (#1) Do you know anything about health care applications & elder home care?

M: Sure. One of the applications that we are heavily involved with would be medical robotics; the medical side of our business makes up more than half of what we do, so we're heavily entrenched in the medical arena, so the robotics is a small portion of that. We do work with surgical robotics such as da Vinci & intuitive surgical, multi-leaf collimators with companies like Varian, but we also do surgical devices, we do little insulin delivery infusion pumps, so we do a lot of different medical applications. as far as home care unit, we do some with some home dialysis machines that might be something that's applicable for elderly patient care. So I would say it's probably a small percentage of what we do currently is intended for the elderly care market or home care market, but I could see that as a growing part of what we do in the future.

I: (#2) Among those applications, which current application do you see as the most effective (in terms of cost, functionality, & profit)?

M: Obviously cost is always a concern...for us with our product we generally are preaching better performance, better reliability, better overall value; the cost of our product may be on the higher side, but because we're offering better reliability & better overall value in terms of service cost, so you know once it's in the field you wouldn't have to replace the motors for a longer period of time as an example, so we think the advantages of our product are well suited for robotics applications; in the medical arena, generally (reliability?) quality generally is the most important factor.
But as far as robotics go in terms of making them widespread in the industry, companies generally are looking for something that's easy to use, something that's reliable, has a certain price point, and is "something that they can interface with technology around it". So I think those are probably the biggest challenges getting involved.

I: (#3) Which area do you feel is developing most rapidly?

M: My guess would be on the rehab & prosthetics side, a lot of military personnel coming back that have lost limbs or need help rehabilitating. also just in terms of medical care in general - I see a big growth area--we're involved with different companies that are making artificial limbs, prosthetic equipment, rehab equipment; so I would say that's probably one of the areas I would see the most growth potential.

I: Which area does the company focus more & more in the future, as a trend (as far as Maxon goes).

M: We see growth in the medical arena as the population ages, so we're trying to position ourselves with all the medical applications, again of which robotics would be a subset of the medical market, but we also see growth opportunities in other industries
Strictly on the robotics side, I'd think the area of surgical robotics will be a big area of growth because the number of doctors that are out there related to the potential number of patients could be a problem down the road, so I think surgical robotics would probably be one of the areas that has the best growth potential.

I: (#4) What is holding robotics back from becoming part of average consumers' daily lives? Cost, acceptance, scarcity of materials?

M: I think all of those are factors. I think in general people are somewhat resistant to change, so they have the acceptance of robots as a part of [that]. I think cost is a big part, especially on the consumer side, and on the health care side; the cost has to be attractive for it to be ingrained within the industry. So I think cost is definitely a factor, acceptance is definitely a factor, and I think ease of use [is another] (have to make it so it fits into a person's daily life). And right now I think to some extent people would still view robotics as something that's kind of a novelty, and that needs to be brought into a more commercially acceptable something where if you see a robot around you, you don't think twice about it, where as now I think people still are drawn to the fascination, but it's not something that's a part of everybody's daily life; but it's getting there, it's definitely getting there, and it will be there in the future.

I: I think the demand is also growing; sometimes the consumer doesn't know what they expect, but if they see the product they will know if they want it or not.

M: Absolutely, I think robotics 20 years from now could be like other technology (i.e. computers), I could see the day when robotics we're surrounded by--every part of our life is affected by robotics down the road, it's just a matter of how long it's going to take to get there.

I: I remember someone telling me about that American people think of robots as an evil image in many movies because robots dominate the human society (something like that). He said that will also influence people's acceptance towards robots used in their daily lives, so what do you think about this?

M: I think there's some truth to that in past, but I think it's changing, I think people are reading about all the work that robots are doing, in the war (bomb detection robots for example). Now if they go to the hospital they're seeing robotic surgical systems, they're starting to see more & more of it, & they're starting to see it in a positive way, which has a useful part [in] society, so I think people's perception of robotics is changing. I think students are getting more involved with robotics at a younger age, so the acceptance level of the younger generation as they get older I think will also help as well.

I: Right, they become the consumers.

M: Absolutely, so if they're used to it at a younger age, by the time they have money from working in a job, they may be more inclined to want to purchase something on the robotics side.

I: (#5) Anything else you would like to add about application of robotics in health care?

M: We're excited about it, from our company's perspective, because of the products we make. The advantages are very well-suited for robot applications, because robot applications are concerned with physical size. They want light weight, they want efficient systems, reliable systems. So we personally see it as a big growth area down the road, again across many different industries. And a conference like today is really nice to be able to network & learn about what else is out there, some of which we don't know about, and you just never know what the future holds.

Quote from Paul McGrath

"People still view robotics as a novelty, so we need to make it into a common consumer product to the point where people won't think twice about robots helping your tasks. People still are fascinated by the technology, but it's a bit hard to accept it into everyday life. Nowadays people see more positive impacts of robotics like robotic surgery systems and bomb robots. We know that students involved at younger ages then become the consumers." (Paul McGrath)

ERIN RAPACKI

Interviewer: (#1) Please introduce yourself. How familiar are you with the application of robotics in health care?

Rapacki: Product Marketing Manager of Adept Technology.

Been in robotics for 10 years from high school robotics team, 6 internships while in northeastern with 5 year preset Co-Op program

Graduate school in UMass Lowell as mechanical engineering. In computer science and robotics lab focused in human robot interactions with rehabilitation.

I: (#3) Do you have any insight into what kinds of robotics technologies are developing quickly?

R: Home care – first robot in your home would be **elder care robot**. A great elder care robot can be built by couple of thousand dollars. You can go to a nursing home with this much of money, but the robots can keep elders in their home by the time the acceptance of elders get grown.

Spying by a robot- 'any convenient' time of a day and it goes back in a corner of house and you get private time (compare this with twice a week nurse visiting your house and interrupt you). Going to nursing home is up to insurance companies, states policies, and doctors. State need organizations or companies to make sure that robot complies what the person's needs and requirements, billings, and qualities of care.

I: (#2) Which area of applications do you think is the most efficient? In terms of cost, functionality, profit and value, in health care?

R: Old people can't use things, good to have a living-assistant system or robot with voice recognition system (like iPhone4S talking app) and object-recognition system. In order to increase complexity, you need data, and with the complexity, the robot will have the value attached to eldercare. Then elderly will think "nursing home sucks".

I: What kinds of technologies will be attached to the system you've talked about?

R: 3D Objects- render any objects and make a 3D model. This can be applied to robots that use a huge 3D objects database with 3D object recognition system. Robots can sell and buy things online by checking those objects online matching with the 3D database.

I: (#3) What area do you think is developing most rapidly in health care?

R: Hospitals- care facility and nursing home. Vecna, and Aetheon are developing autonomous mobile platforms in hospitals. Point-to-point navigation system, mapping system, etc.

Telepresence surgery/diagnosis is another area will grow rapid. This is based on a one big broad-band connection of the world, which is happening right now.

I: (#4) What is holding robotics back from getting into our daily life? Cost? Acceptance?

R: Technology is there, but people who understand markets well enough to fill the technology in meaningful ways and people who understand markets well enough to see connections and draw big pictures. There are many big problems and more and bigger that are not known. Some people see the problems, but they do not understand robotics (the technology). Therefore, the key is to match needs and technology.

I: (#5) Is there anything else you would like to add?

R: The material handling in hospital, nursing home, and other caregiving facilities, and idea of mounting something on a wheelchair such as personal assistance robots are developing, like cafeterias and kitchens that have assistance systems.

Many researchers who are self-citing; a narrow-citation range can cause movement in a wrong direction in the research. [Be aware of research going on elsewhere in the industry and the world.]

Robots can't do much, people don't want them to do much, or they can't afford for them to do much. Do simple things right first!

Quotes from Erin Rapacki

"the first robot in our home will be an elder care robot for people who want to stay home with privacy by spending couple thousand dollars instead of going to a nursing home."

Appendix D: Coding

To analyze and process data team achieved from interviews with industry experts and focus groups with WPI students and patients and caregivers in Summit Elder Care, we decided to code the data.

Primary Coding for Summit Elder Care

Acceptance

- Culture
  - Privacy
    - “Somebody has to be with me all the time; I fall too much.” – *elderly woman* – privacy is not a concern when safety is in question.
    - Participants don’t mind doctor checkups.

      (on eNeighbor)
    - "To me, that would be a good thing. **I don't think it's invading privacy**, not when it's someone who does need help, and could need you in the middle of the night or day." – *caregiver* .
    - "I think when people are young adults, they need to go work in a nursing home or rest home or spend a few days here [summit], and ride the vans and do everything that is done for these people [summit participants] and they **wouldn't worry about privacy anymore. It's for their lives**." – *caregiver.*
  - Independence
    - female, table: would prefer doing some things herself
    - caregiver, female, right - **want independence**, but have anxiety from giving that independence (falling) - human interaction complicated, but allows for this independence - know how much to give & take
  - Role of Human
    - to male, table: with this kind of assistance, would living at home be better (less boring/lonely)? - have wheelchairs & walkers, machines can help a bit, but **need someone to help** even with machine
    - caregiver, female, right: "I could see them [robots] helping, but **they'll never replace TLC**." need a combination - person & machine
    - summit: interaction, quick/attentive medical care, opportunity to get out and do something
    - could be attached to people that take care of them at home - some of each, **but not total "robot replacement"**
    - can't replace real companionship from human/pet
  - Uncanny Valley

      (on Paro)
    - caregiver, female, right: almost creepy
    - caregiver, male, right: "**Depends on person who is using it and their abilities**. If they've got all their faculties, it may not do much for them. For somebody with serious dementia, it may [work well]."
    - caregiver, female, left: "I would rather have a dog than a seal." (robot or real?)
- Cost

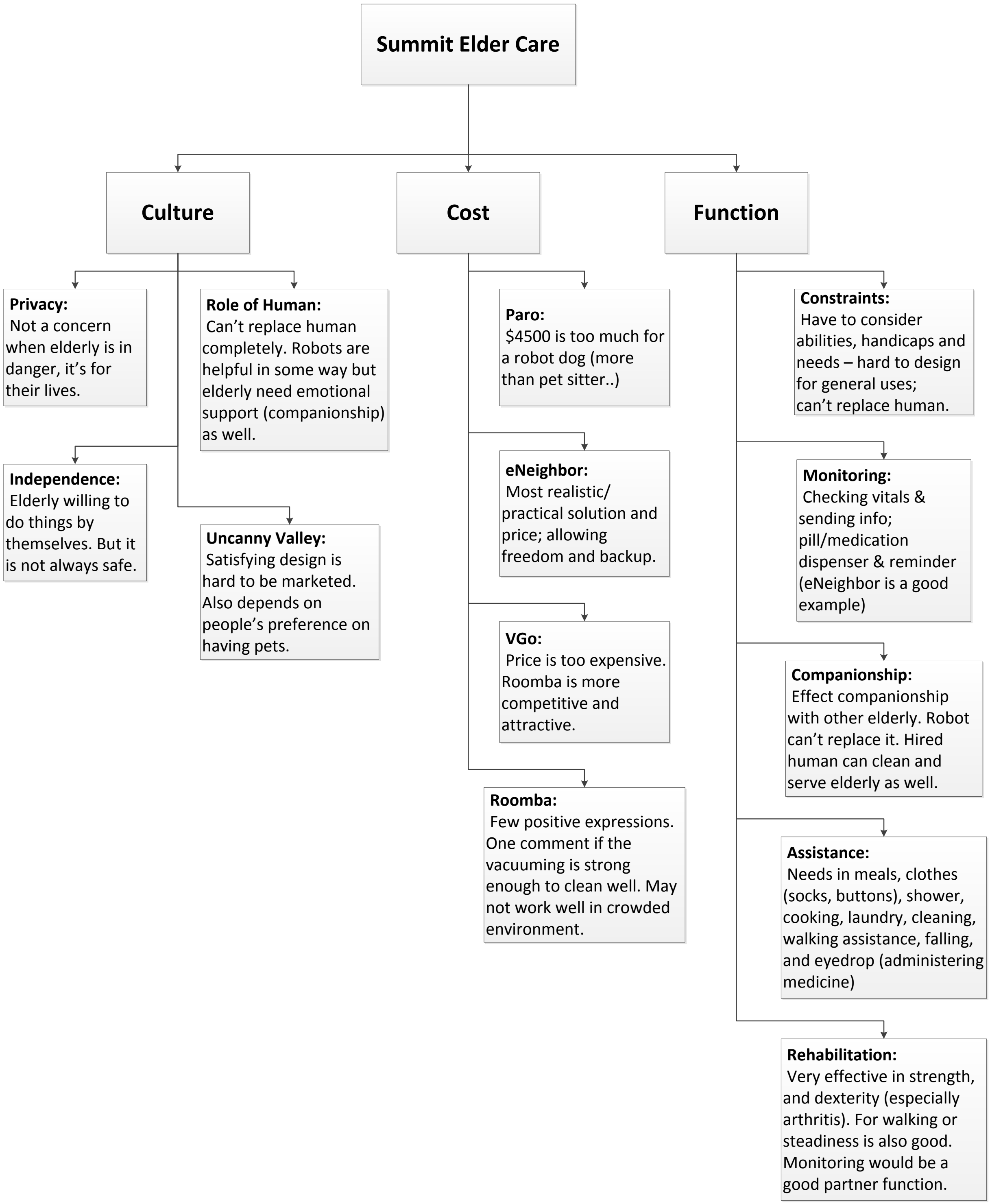
- (on eNeighbor)
  - caregiver, female, left: looks like most realistic solution/device; more freedom, backup, **more realistically priced**
- (on Paro)
  - caregiver, female, left: **"I couldn't spend $4500** on that...I could pay a pet sitter full time to take care of a pet for less than that."
- (on VGo)
  - female, table: thinks prices are far **too expensive** for just a piece of equipment (PARO, VGo), but would like to get Roomba ("and see it move" - not sure if she believes it will actually vacuum, or if she will have it as a novelty)

- Function
  - Assistance
    - female, table (what her daughter helps her with at home) (personal care)
      - gets all **meals**
      - gets out her **clothes**
      - would help with **washing**, but participant doesn't allow help with that
      - a lot! (**too much**, she likes to do some things for herself)
    - male, table (personal care)
      - "without anybody at home, I could never do anything"
      - needs help with: **cooking** breakfast, **showering**, **cleaning** the house
      - hard time **walking**: cane -> walker -> wheelchair (for bus)
      - **falling** more (5-6 per year?)
    - eyedrops (administering **medicine**)
    - help **dress** (socks, buttons)
    - currently: **dress, , supper**, etc. (what they need before summit) **breakfast, shower**
    - caregiver, female, left: [machines giving medication wouldn't diminish independence much & would give more time for interaction & other activities]
    - female, table: something to **clean**
  - Monitoring
    - caregiver, female, left
      - something to **check vitals & send info** to Summit before participant arrives
      - **pill/medication dispenser & reminder**: (morning, evening pills), monitor whether pills were given/taken

      (on eNeighbor)
    - caregiver, female, left: looks like most realistic solution/device; more freedom, backup
    - caregiver, female, right & female, table: has lifeline [similar product, less advanced]
    - caregiver, male, right: "important to know when Alzheimer's patients are on the move”
    - **ease of mind, backup** even if someone was living with elderly person
    - "If I were you, and I were designing this, I would shift totally toward the actual informational side of things. If you take away the human contact, then you're not going to need any of the rest, so you're spending money in a way that isn't going to matter."

        - Conrad: more proactive approach, system monitoring health could diagnose diseases & problems at much earlier stages, and increase quality of life.
        - male, left: caregiver tries to **prevent entry into nursing home** for as long as possible, and **eNeighbor** could do something like that
    - Companionship
        - can't replace real companionship from human/pet
            - taught to play rummy
            - female, table - 2 kittens at home, 1 is "hers" - couldn't replicate the real thing
        - summit: interaction, quick/attentive medical care, opportunity to get out and do something
        - **interactive game**
            - simple game of rummy is legitimate
            - "most seniors do some type of puzzle daily"
            - just got Kinect, hard to get it setup & get to game - **user friendliness**
        - "Would you prefer a machine to do all these things for you [the caregiver], or do you like the fact that it's a machine helping him?"
            - caregiver, female, right: personal contact very important
        - gets all cleaning/service from hired help
    - Rehabilitation
        - make up for **arthritis** (hands) - strength, dexterity
        - caregiver, female, left: **walking or steadiness** - like a walker, but updated to monitor
    - Constraints
        - (on eNeighbor) more realistically priced
        - have to consider **abilities, handicaps & needs**, specific for each person
            - one person at summit can't talk - no voice commands/communication
        - caregiver, male, right: **depends on needs**, nothing would cover everyone's needs, individual decision
        - can’t replace human
        - (on Roomba) may not work with many living spaces (split-level, crowded), true for all robots

Visualized/Advanced Coding for Summit Elder Care



Primary Coding for WPI Focus Group 1

Acceptance

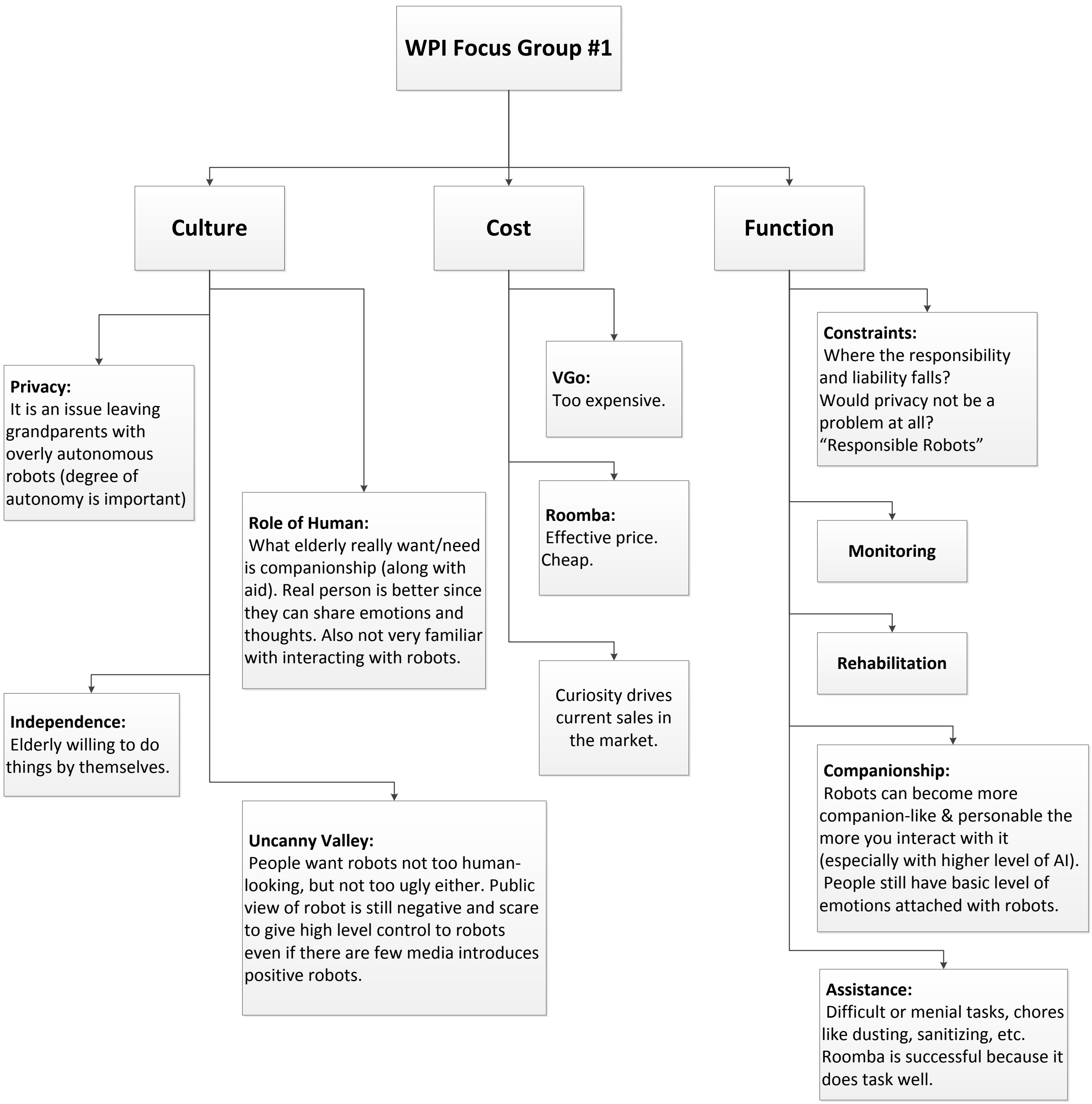
- Culture
    - Privacy
        - one would want "intelligent/robotic" laundry machine, but wouldn't want something walking around, monitoring, & <u>controlling</u> - <u>extent of autonomy</u>
        - question of privacy w/roaming or intrusive robots - <u>especially leaving grandparents with them</u>
    - Independence
    - Role of Human
        - letting go of control - self-driving cars - computers make less mistakes, but it's scary
        - H: STS2208 - "What is the exact reason why people are afraid of technology?" Worried tech may go wrong or rogue/haywire? Is it because the public doesn't know much about the tech? Or just purely from media/propaganda?
            - can make people feel useless, gets rid of jobs (but have vending machines & ATMs)
        - one person doesn't want robot to do too many things that they already do, would feel useless
        - what the elderly really want/need is <u>companionship</u> (along with aid) - not take place of humans
        - C: Any difference (independence-wise) between humans & robots taking care of someone at home?
        - Add human element - add millions of variables (emotions, corruption, greed, OR very kind, in tune) - robots more predictable & reliable "unless the creator makes it in his or her image" [!?]
        - elderly at home, wants person to take care of them, personal nurse (cook, clean, wash, games), better for elderly b/c they show emotions & thoughts, not black & white
        - K: Products like this more popular in the future?
            - no - high price, <u>losing human interaction</u>
    - Uncanny Valley
        - uncanny valley - too close to human, very creepy (both in appearance & autonomy) - has human capability & intelligence (or greater), but not human morals
    - Perception of Robots/Technology
        - some people want robots that can think for themselves, but that scares a lot of the general population
        - giving control to robot scary because of modern portrayal in movies/TV? (iRobot movie)
            - K: professional at RoboBusiness said that view could be turning around, because robots more commonly seen being helpful (bomb defusal, surgery)
            - participants didn't seem too convinced that public view was becoming positive
        - fear comes from autonomy - many military robots <u>under human control</u> [in this way, are they even robots?] - partially autonomous

        - tangent?: "I wonder if the general public is truly aware of the level of autonomy that these robots (i.e. semi-autonomous vehicles) actually have, and if they were fully aware, if that would change their opinion"
        - people afraid of them becoming more autonomous - snowball effect - afraid of what they might become – portrayals
        - T: Our generation comfortable with robots? Will we have them around to aid us? - depends on how threatening they seem; now they aren't threatening b/c very simple
        - could be marketed in a friendly way
        - the more prevalent robots become, the more comfortable people will be around them, & they will see their usefulness
        - many elderly very undereducated & wary when it comes to tech (i.e. internet) - even less likely to trust if children or grandchildren not comfortable with it - would have to introduce gradually or *very* positively & carefully
        - C: Do people even see it as a robot, or more of a "glorified vacuum cleaner"? That might have something to do with its success.
            - people expect more when they hear the term robot - Roomba is far from that?
            - C: easier to accept because it has simple functionality
        - robotics an expensive, low-functionality field at the present moment - a <u>novelty</u>
- Cost
    - curiosity drives current sales
    - Roomba cheap
    - VGo too expensive
- Function
    - Assistance
        - assistance - difficult or menial tasks[1]
        - another person likes the idea of cleaning robots (dusting, sanitizing, etc.)
        - (on Roomba) K: Why do you think it has become so successful? Price? Functionality? Lucky?
            - pass off menial task to something that does it well
    - Monitoring

    - Companionship
        - robots can become more companion-like & personable the more you interact with it (especially with higher level of AI)
        - human-like traits for inanimate objects - Roomba: clothing line, want that specific robot back from repairs - obviously people still have emotional attachment
    - Rehabilitation
    - Constraints
        - [1] K: not ready to do important tasks? - robots ideally suited to monitoring (vital signs, behavior (not there yet)) - more than monitoring, <u>robot becomes responsible</u> for health, maybe not at that point yet (technologically) - not ready to care for someone with a high degree of responsibility
        - question of privacy w/**roaming** or **intrusive** robots

- tangent?: medical care, liability; elderly should be reminded to take medicine, but robot didn't remind them to or didn't dispense medicine (error) - where does the liability fall?

Visualized/Advanced Coding for WPI Focus Group 1



Primary Coding for WPI Focus Group 2

Impact of robots in home setting

- Elderly tend to be physically unable to complete tasks
- Unaware that tasks need to be done (elderly with dulled senses)
- Little robots with specific tasks dispersed throughout house
- Automate appliances/tasks already in place
- Automated appliances lack personal/companionship aspect
- Can you even get companionship from a robot? Probably not- maybe from dog

What role could robots play?

- Checking in with elderly
    - Ease worry about leaving grandparents alone
    - Don't have to rely on grandparent remembering/being able to get help (forget button, hit head)
    - As user, I want to know as much about robot as possible. Keeping tracking on robot keeps tracking on my grandparents or parents (in the future)
    - Need to know how the (monitored) info would be using or going to

- Smart home
    - Force/seismic detector in floot (determine if someone falls)

- Medicine dispenser
    - Won't forget or be confused by pills
    - No access to wrong pills
    - Call in for refills
    - Identification (fingerprint/breath) could prevent medicinal abuse

Giving robot responsibility over potentially life-critical medicines?

- Pill managing robots already in use professionally
- Keep tabs on information, careful monitoring, no problem
- Implement failsafe – emergency or immediate medication
- Identification (repeated)

Transportation in scenario

- Drive back and forth to doctor's office
- Google car – emergency stop button
- Machines should make less mistakes than humans
    - Seems many people are wary nowadays (mixed population- techy+non-techy)
    - Missing human element & judgment that is impossible to translate to programs

Housekeeping in scenario

- Smart appliances (fridge ordering groceries)
- Help people keep up on important chores/tasks

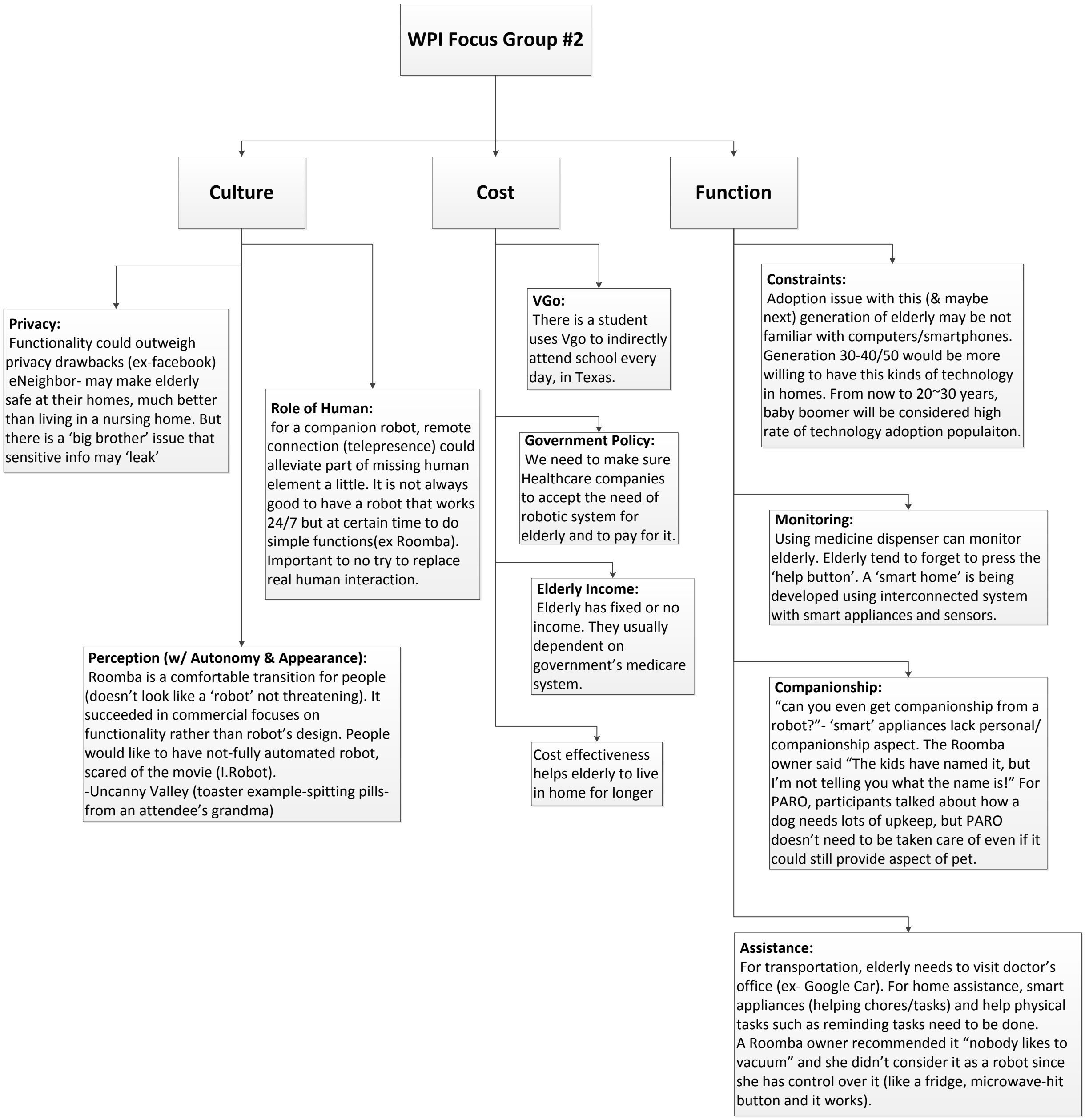
Acceptance/adaptation conditions

- Adaption issue with user friendliness with this (and maybe next) generation of elderly who did not grow up with computers/smartphones
- Age/generation of 30, 40, 50s would be more willing to have this kind of tech in their homes
- Facebook- 800M users post private info, however functionality could outweigh privacy drawbacks
- Also note the age range of Facbook users

Key features/functionalities for all robots

- Companion robot very difficult to pull off, Human/living element is missing
- Remote connection (telepresence) could alleviate that a bit
- Robots usually good for chores, etc even if many years away from perfection
- It seems smart house (Ubiquitous) would come sooner than companion/free-roaming
- Smart house with interconnected system (appliances, sensors) controlled by smartphone
- Google IO – almost close with smart house
- Technology level for smart houses is close enough that they will be in full swing when accepting generations need them

Visualized/Advanced Coding for WPI Focus Group 2



Appendix E: Poster